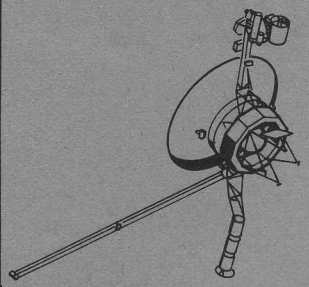

MISSION STATUS BULLETIN

VOYAGER

August 9, 1977 **No. 1**

MISSION PLAN

Less than one month from today, about August 20, man will begin another journey into outer space, searching the heavens for answers to age-old questions. The National Aeronautics and Space Administration's Voyager Project will send two advanced Mariner-class spacecraft to fly past the outer planets Jupiter and Saturn, and perhaps, Uranus, gathering scientific data on these giants and their satellites, as well as on interplanetary space itself.

If all goes according to schedule, two years to the day after the launch of the Viking Mission to Mars, the first of two Voyager spacecraft will be catapulted on a trajectory which will target it for arrival at Jupiter in April, 1979, with closest approach in July. About twelve days after the first launch, a second spacecraft will follow. Due to planetary alignments and other trajectory considerations, this second ship, designated Voyager 1, will overtake the first-launched and arrive at Jupiter four months in advance of it, beginning its observatory phase in December, 1978. Therefore, the first-launched craft will be designated Voyager 2, as it will become the later arrival at the target planets.

The Voyager spacecraft are unique in many respects. Their launch will mark the end of an era in space travel, being the last planned use of Titan III/Centaur launch vehicles. With the advent of the Space Shuttle in the 1980's, spacecraft will be launched from the Shuttle Orbiter.

Electrical power for the Voyager will be nuclear-fueled, using radioisotope thermoelectric generators (RTGs), rather than the solar panels used by the Mariners and Viking Orbiters. The Voyagers will travel perhaps 30 times as far from the sun as man has yet ventured, and at this distance, the solar energy available for capture and use will be greatly diminished, necessitating a more effective power source. RTGs have been used successfully by Pioneers 10 and 11.

The power usage of the 11 scientific instruments mounted aboard each spacecraft will be less than that of a 100-watt light bulb.

In the planned 8-1/2 years of the mission, Voyager will gather data on perhaps 15 heavenly bodies, the asteroids, and interplanetary space. While the primary targets are the planets Jupiter and Saturn, their satellites are as of great importance in providing clues to the universe, and thus the mission plan includes scrutiny of at least 11 of these satellites. An option exists to propel Voyager 2 on past Saturn to Uranus, seventh planet from the sun. Arriving in 1986, Voyager would provide the first close look at the rings of Uranus just discovered in the early part of 1977.

CURRENT STATUS

Failures in the Attitude and Articulation Control Subsystem (AACS) and Flight Data Subsystem (FDS) on the VGR77-2 spacecraft planned to be launched August 20 have resulted in a decision to interchange the two flight spacecraft.

First launch is still scheduled for August 20, the first day of the 30-day launch window. The VGR77-3 spacecraft will now take the first launch date. Switching of the two spacecraft can be accomplished with minimum risk to the targeted launch date since the VGR77-3 schedule has always been predicated on the capability to support the August 20 date.

All testing and checkout of the VGR77-3 spacecraft continues at the Eastern Test Range (ETR), Cape Canaveral, Florida, with the pre-countdown test scheduled for August 8. Encapsulation in the spacecraft shroud is scheduled for August 9, with mating to the TC-7 Titan/Centaur launch vehicle at launch pad 41 planned for August 11.

The failed AACS and FDS have been returned to the Jet Propulsion Laboratory in Pasadena, California. The spare AACS and a repaired FDS may be available for reinstallation in VGR77-2 at ETR by August 10, which could result in an encapsulation date of August 17.

Weight and center-of-gravity measurements conducted June 25 for VGR77-2 and July 16 for VGR77-3 included the gold-plated "Sounds of Earth" recording which will carry goodwill messages from man to the universe.

Mission Operations at Pasadena continues to generate sequences and perform test and training exercises. The operational readiness test was conducted August 2, and the Mission Operations Readiness Review was held August 5 and 6. Telemetry data flow verification tests are scheduled for August 8 and 12, with a full-up operational readiness test involving all elements in a launch configuration scheduled for August 15.

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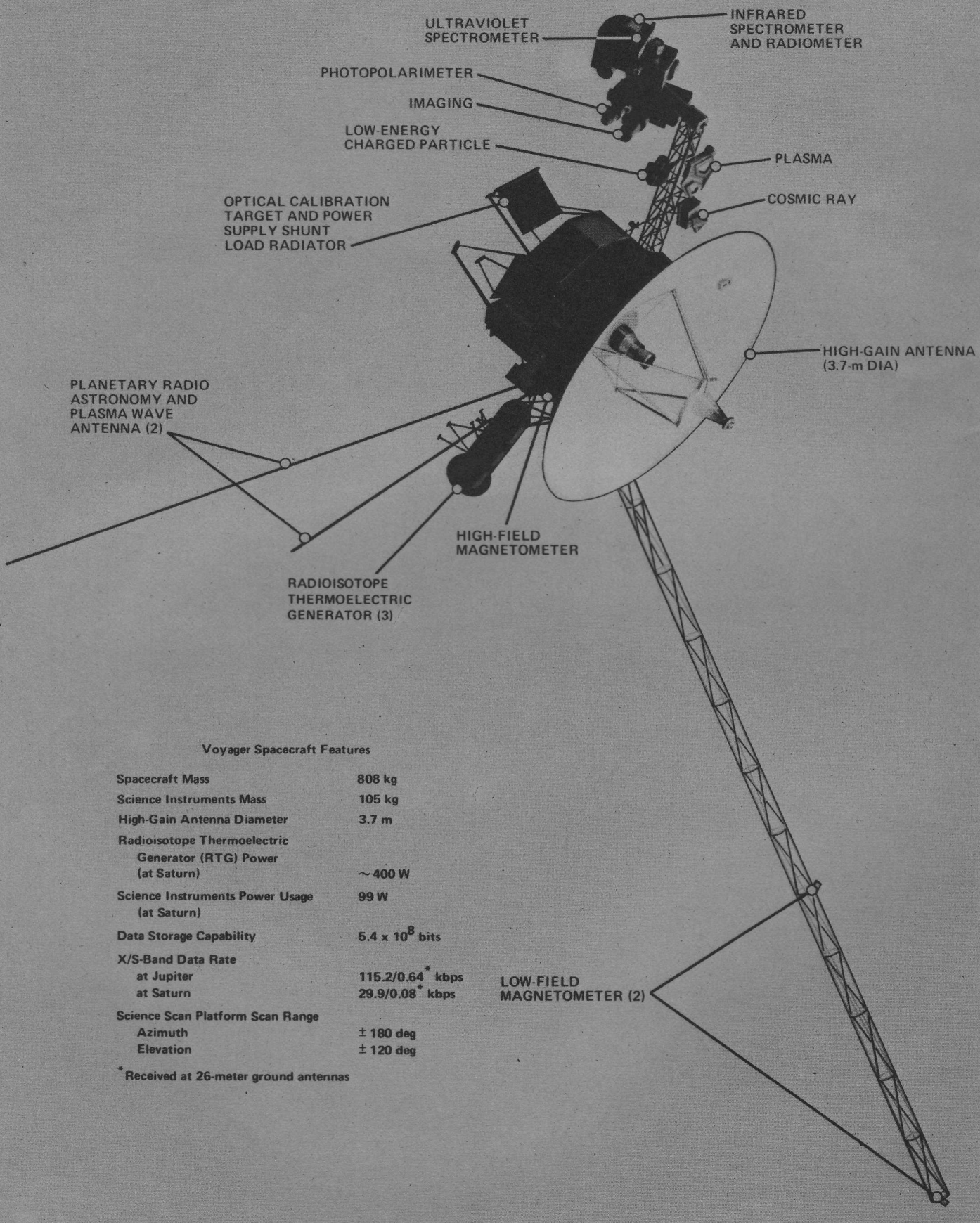
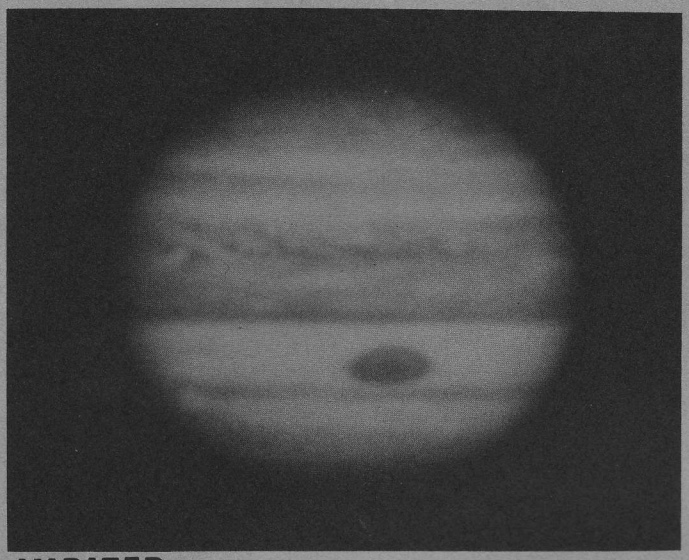


Voyager Spacecraft Features

Spacecraft Mass	808 kg
Science Instruments Mass	105 kg
High-Gain Antenna Diameter	3.7 m
Radioisotope Thermoelectric Generator (RTG) Power (at Saturn)	~400 W
Science Instruments Power Usage (at Saturn)	99 W
Data Storage Capability	5.4×10^8 bits
X/S-Band Data Rate	
at Jupiter	115.2/0.64* kbps
at Saturn	29.9/0.08* kbps
Science Scan Platform Scan Range	
Azimuth	±180 deg
Elevation	±120 deg

*Received at 26-meter ground antennas



JUPITER

Jupiter: fifth planet from our sun, largest in our solar system, named for the mighty god of Roman mythology. The giant planet, Jupiter, with its bright red and yellow bands and Great Red Spot, contains 98 percent of the matter in the solar system excluding the sun, radiates more than twice the amount of energy it receives from the sun, and may be composed of the same primordial constituents as formed the solar system nearly 4.6 billion years ago.

Five of its 13 or 14 known satellites are composed of Jovian elements; the outer satellites appear to have been formed outside the Jovian system and captured by its gravity as they passed the great giant. The density of the satellites decreases with increasing distance from the planet. One, Io, has been discovered to have both an atmosphere and an ionosphere.

Jupiter does not have a solid surface. All that is visible to man is its atmospheric pattern. Since the elements (hydrogen, helium, ammonia, methane and water) thus far detected on Jupiter by spectroscopy are colorless gases, much speculation exists as to the cause of the bands of color and the red spots.

The magnetic field of Jupiter is also intriguing. Voyager's scientific instruments will measure the limits of the magnetosphere and its interaction with its satellites and the solar wind, which is 25 times weaker at five times farther from the sun than is Earth.

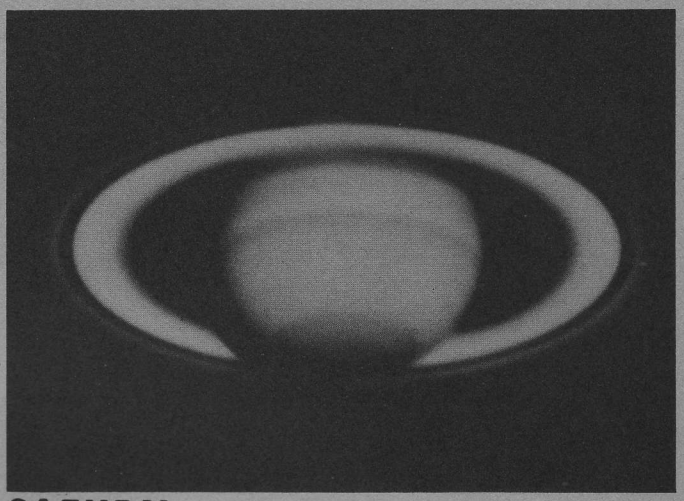
The four Galilean satellites, Io, Europa, Ganymede, and Callisto, discovered by Galileo in 1610, are large and bright enough to be seen by the unaided eye, if they were not occluded by the brilliance of Jupiter. Tiny Amalthea, innermost of the satellites, will also be surveyed.

Voyager's closest approach to Jupiter will occur in March 1979, at a distance of about 280,000 km. As it passes Jupiter on its trek to Saturn, it will also scan the Galilean satellites and Amalthea.

Voyager 2 will encounter the same five satellites before its closest approach to the planet itself in July 1979, from a distance of 645,000 km.

Voyager will significantly add to the exploratory data collected by Pioneers 10 and 11, providing a wealth of scientific information and laying further ground work for the next planetary exploration, Jupiter Orbiter/Probe, to be launched in 1981, which will deploy a small probe to tickle the atmosphere of Jupiter. Voyager's imaging system will provide the best pictures man has ever obtained of Jupiter, with such resolution that the Great Red Spot (40,000 km x 13,000 km) will fill 40 camera frames.

After a final look at the Jovian system, Voyager will turn toward its next goal, Saturn.



SATURN

Saturn, sixth planet from the sun, has yet to be visited by planetary spacecraft. Pioneer 11 will provide the first non-telescopic look at Saturn in September 1979 and 11 months later, in August 1980, Voyager 1 will enter the planet's territory. Voyagers 1 and 2 will survey Saturn, its rings, and six of its ten known satellites, Mimas, Enceladus, Tethys, Dione, Rhea, and the largest, Titan.

Telescopic observations show that Saturn is also banded, although not as definitively as Jupiter. Most distinctive feature of Saturn is, of course, its celebrated rings. First observed by Galileo in 1610, the rings remain an enigma. Various theories propose the composition of the four observed rings to be ice, rock, or metallic particles, ranging in size from four to 30 cm. It is certain that the rings are not solid and that they are not a thick band.

When the system is viewed edgewise from Earth, the rings are practically invisible, and have been determined to be about 10 km thick. The broadest ring is about 26,000 km wide, while the radius of the entire ring system is 140,000 km.

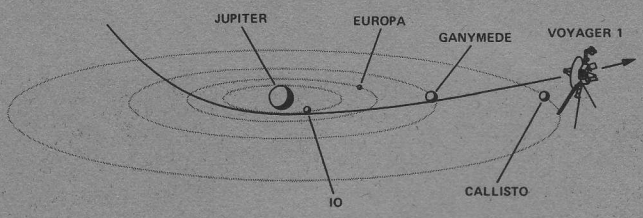
Voyager 1 will sail to within 4000 km of Titan's surface, and then will pass about 140,000 km below Saturn's south pole, about November 13, 1980. As it passes out of the Saturnian system it will fly through the ring plane, survey the north polar area of the planet, and encounter five more satellites.

Voyager 2 will enter Saturn's domain in June 1981, surveying the same six satellites and the rings, but from a more cautious distance. If all goes well, Voyager 2 may use the gravity of Saturn to boost itself towards Uranus, and its instruments must be in excellent operating condition for encounter with the seventh planet of the solar system.

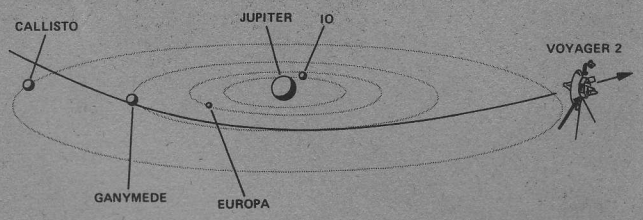
URANUS

Uranus was discovered in 1781 by Englishman William Herschel. Nearly two centuries later, in early 1977, James Elliott of Cornell University announced the startling discovery of Uranian rings. Voyager 2 may provide the first observation of the planet by a spacecraft, arriving in January 1986, over four years beyond Saturn.

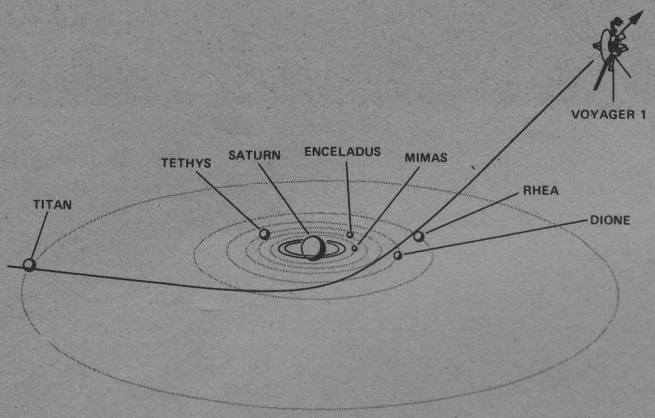
Thus, if all goes according to plan, in 8-1/2 years, the Voyager project will have surveyed more than 14 celestial bodies and interplanetary space with a depth and clarity never before achieved.



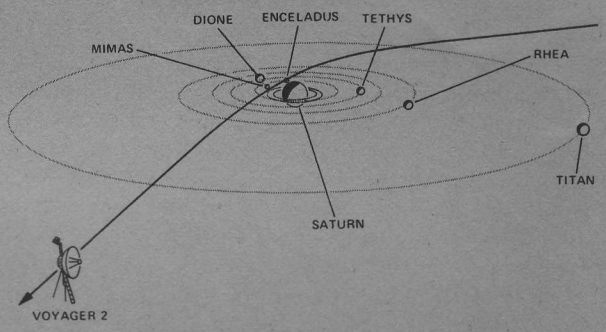
Voyager 1 will begin its Jupiter observatory phase about December 15, 1978, making its closest approach at about 280,000 km to the planet's visible surface about March 5, 1979. It will observe five Jovian satellites on its outbound leg.



Voyager 2 will begin its Jupiter observatory phase about April 20, 1979. The craft will observe the same five satellites on its inbound leg, before its closest approach to the planet at about 645,000 km.



Voyager 1's observations of Saturn will begin in August 1980, with closest approach at about 140,000 km in November 1980, Voyager 1 will pass through the ring plane as it observes six Saturnian satellites.

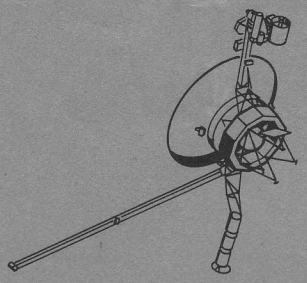


In June 1981, Voyager 2 will begin observations of Saturn and the same six satellites. Closest approach, at about 38,000 km from the outer edge of the rings, will be about August 27, 1981.

(Note: These computer simulations of the Voyager trajectories show each spacecraft's closest approach to each of the target bodies. Amalthea, Jupiter's nearest satellite, is not visible in these views.)

SCHEDULE

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
LAUNCH	AUGUST									
JUPITER ENCOUNTER –80 DAYS, V1		DECEMBER								
JUPITER ENCOUNTER, V1			MARCH							
JUPITER ENCOUNTER –80 DAYS, V2			APRIL							
JUPITER ENCOUNTER, V2			JULY							
SATURN ENCOUNTER –80 DAYS, V1				AUGUST						
SATURN ENCOUNTER, V1				NOVEMBER						
SATURN ENCOUNTER –80 DAYS, V2					JUNE					
SATURN ENCOUNTER, V2					AUGUST					
URANUS ENCOUNTER, V2									JANUARY	



MISSION STATUS BULLETIN

VOYAGER

August 16, 1977 **No. 2**

CURRENT STATUS

VGR77-3 (Voyager 2)

All project elements participated in the practice countdown and operational readiness test on August 15 in preparation for the August 20 launch of VGR77-3. The pre-countdown tests August 13 and 14 included readouts of the memories of the spacecraft's three on-board, reprogrammable digital computer systems, the Command Control Subsystem (CCS), Attitude and Articulation Control Subsystem (AACS), and Flight Data Subsystem (FDS).

The VGR77-3 spacecraft was encapsulated August 9, but was removed from the shroud when the post-encapsulation electrical tests detected a need to electrically ground the low energy charged particle (LECP) instrument. The LECP was changed and the spacecraft reencapsulated August 10. Post-encapsulation electrical tests were satisfactory, and VGR77-3 has been moved to launch complex 41 and mated to the Titan/Centaur TC-7 launch vehicle in readiness for launch August 20.

The decision to switch the flight spacecraft necessitated switching of the radioisotope thermoelectric generators (RTGs) as well. Since the first launch trajectory includes the option to extend the mission to Uranus, a distance of 19 astronomical units (AUs) from the sun, the higher power output RTGs previously installed on VGR77-2 were removed and reinstalled on VGR77-3.

VGR77-2 (Voyager 1)

VGR77-2 is scheduled to be launched as soon as ten days after the first launch, but will be available by August 18 to support the first launch if necessary.

An intermittent hardware condition associated with the clock function was detected in the VGR77-2 AACS telemetry. Because of this problem, the AACS proof test model (PTM) was installed to fly on VGR77-2. The FDS computer has been reinstalled on VGR77-2 following troubleshooting, repair, and retest of an intermittent hardware condition affecting the checksum routine.

Pyro checks were completed August 13 and the pre-countdown test will be conducted August 16. RTG installation and spacecraft encapsulation is scheduled for August 17.

LAUNCH DAY ACTIVITIES

All JPL employees, contractors, and their families are invited to view the Voyager launch activities Saturday, August 20. Launch is scheduled for 7:30 a.m., PDT, and the Laboratory facilities will open at 6:30 a.m.

Launch activities will be presented via live audio from Cape Canaveral, Florida, and there will be three seating areas available: von Karman Auditorium (Bldg. 186), 180-101 conference room, and the conference room adjacent to the main cafeteria (Bldg. 167). Parking will be available in the visitor and adjacent parking lots. The main cafeteria will be serving from 5:30 a.m. to 3:00 p.m.

Launch events commentary from Kennedy Space Center will be broadcast from approximately 7:00 a.m. to 8:30 a.m., PDT. Spacecraft events will be televised from JPL from approximately 8:30 a.m. to 11:30 a.m., PDT.

The program will be videotaped for replay on Monday, August 22, at 10:00 a.m., 12:00 noon, and 2:00 p.m. on the monitors in the main cafeteria (Bldg. 167), lower cafeteria (Bldg. 190), and the Voyager Project Areas in Bldgs. 230 and 264.

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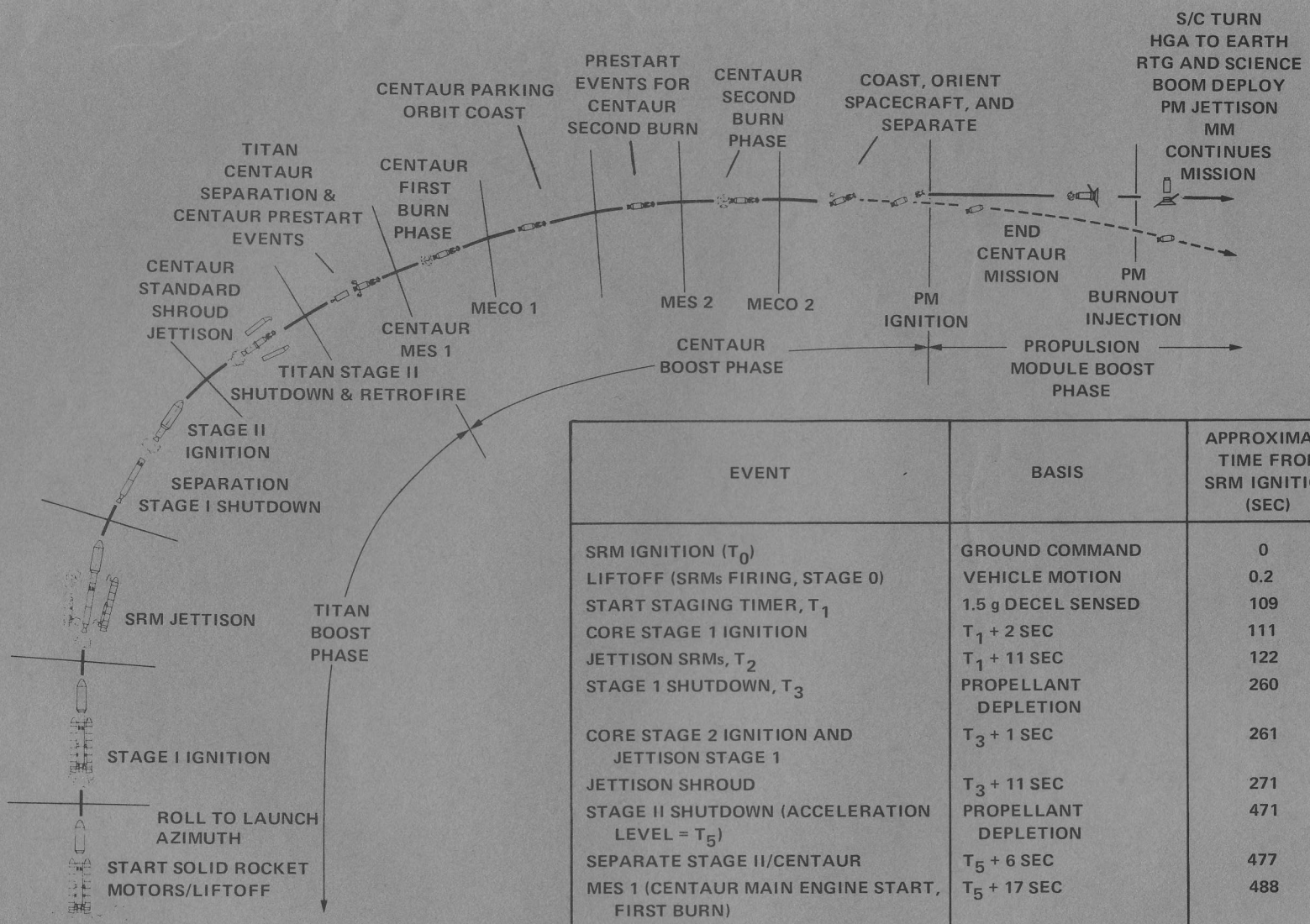
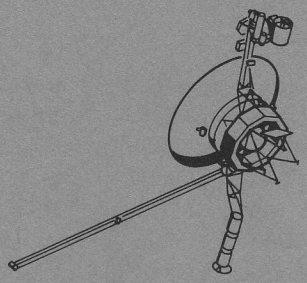


EVENT	BASIS	APPROXIMATE TIME FROM SRM IGNITION (SEC)
SRM IGNITION (T_0)	GROUND COMMAND	0
LIFTOFF (SRMs FIRING, STAGE 0)	VEHICLE MOTION	0.2
START STAGING TIMER, T_1	1.5 g DECEL SENSED	109
CORE STAGE 1 IGNITION	T_1 + 2 SEC	111
JETTISON SRMs, T_2	T_1 + 11 SEC	122
STAGE 1 SHUTDOWN, T_3	PROPELLANT DEPLETION	260
CORE STAGE 2 IGNITION AND JETTISON STAGE 1	T_3 + 1 SEC	261
JETTISON SHROUD	T_3 + 11 SEC	271
STAGE II SHUTDOWN (ACCELERATION LEVEL = T_5)	PROPELLANT DEPLETION	471
SEPARATE STAGE II/CENTAUR	T_5 + 6 SEC	477
MES 1 (CENTAUR MAIN ENGINE START, FIRST BURN)	T_5 + 17 SEC	488
MECO 1 (CENTAUR MAIN ENGINE CUTOFF, FIRST BURN)	PARKING ORBIT (GUID.)	580
MES 2 (CENTAUR MAIN ENGINE START, SECOND BURN)	COAST PERIOD (GUID.–VARIABLE)	3132
MECO 2 (CENTAUR MAIN ENGINE CUTOFF, SECOND BURN)	(GUID.)	3488
S/C -- CENTAUR SEPARATION	MECO 2 + 170 SEC	3658
PROPULSION MODULE IGNITION	SEPARATION + 15 SEC	3673
PROPULSION MODULE BURNOUT (INJECTION)	IGNITION + 45 SEC	3718

Launch Profile for a Typical Titan/Centaur Two-Burn Mission Launch



MISSION STATUS BULLETIN

VOYAGER

August 22,1977 **No. 3**

VOYAGER 2: AUGUST 20, 1977 10:29:45 a.m., EDT

STATUS SUMMARY

Voyager 2 Canopus acquisition is planned for August 23. In-flight science boom testing will be conducted on August 24. A trajectory correction maneuver is planned for August 28.

VGR77-2 will be de-encapsulated August 22 to inspect the science boom. Launch is now scheduled for September 3.

CURRENT STATUS

Two years to the day after the launch of the Viking Mission to Mars, Voyager 2, aboard a Titan IIIE/Centaur launch vehicle, lifted off launch complex 41, Air Force Eastern Test Range (AFETR), Cape Canaveral, Florida. Lift-off came at 10:29:45 a.m., EDT, less than five minutes into the launch window on the first day of the 30-day launch period. The countdown went smoothly except for a brief unscheduled hold at launch minus five minutes to determine the open/closed status of a launch vehicle valve. Minutes after launch, however, several problems were noted.

The problems included a suspected gyro failure, incomplete data transmission, and uncertainty as to the deployment of the science platform boom. The gyro is working now, the data transmission is good, and the science boom appears to be nearly deployed.

Science Boom

The boom supporting the science scan platform was to be released and deployed about 53 minutes into the flight, but initial data gave no confirmation that the boom is extended and locked. When the boom is within 0.05 degree of normal deployment, a microswitch on the folding boom opens. Confirmation of the microswitch position has not been received. A faulty switch could be the root of the problem.

Twelve hours after launch, flight controllers turned on the plasma science instrument, which is located on the scan platform, and used its measurements relative to a known axis and the direction of the solar wind (supplied by Goddard Space Flight Center) to determine the position of the science boom. Indications are that the boom is extended to at least within 2 degrees of full deployment.

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In-flight tests of the boom are scheduled for August 24. Further measurements, including temperature, will be monitored to further assess the boom position. The wide angle camera of the imaging subsystem may be activated to take a series of three star-field photographs from which analysts could more closely determine the boom and platform positions.

There are indications that the scan platform has slewed successfully, but project personnel will assess the AACS data before commanding any more movement of the platform which supports four of the science instruments.

Data Transmission

Data received at earth in the early hours of the flight were faulty and incomplete, but later transmissions began to relay more reliable data. Analysis of later data indicates that the on-board computers operated flawlessly, switching processors and enabling fail-safe routines at the first hint of trouble. Indications are that the data losses were due to an external event, still to be determined, during the launch phase, rather than to a fault in the computer systems.

Also during the Titan burn, the spacecraft switched to its second AACS processor, as part of a built-in fail-safe routine. Because of this, flight controllers will examine the contents of the AACS memory to determine if the commands for Canopus acquisition are still intact, prior to commanding the start of Canopus search. Canopus acquisition is scheduled for August 23. Once locked on both the sun and the star Canopus, the spacecraft will be stabilized on three axes in celestial lock.

The spacecraft has been stable since 3:00 p.m., EDT, August 20, except for a short pitch and yaw disturbance at 5:00 a.m., EDT, August 21. Flight controllers are investigating possible causes of the activity.

After spacecraft stabilization, ground controllers played back the launch sequence events tape recording from the on-board computer. Examination of this tape is needed to fill the gaps in the earth-received data and to determine the launch events which might have caused the data losses.

Gyros

During the Titan burn of the launch sequence, an apparent fault was detected in the Attitude and Articulation Control Subsystem (AACS) inertial reference unit gyros. The spacecraft is equipped with three gyros for orientation, each positioned about two orthogonal axes. Any combination of two gyros can control the spacecraft. During launch, gyros B (roll and pitch) and C (yaw and roll) were active. The on-board computer switched to gyros A (pitch and yaw) and C when the fault was detected, and then to gyros A and B when the apparent fault continued. Indications were that gyro C was not functioning normally; however, since the spacecraft has stabilized, gyro C appears to be operating normally and the active pair is once again the B/C combination in use at lift-off.

Sun acquisition was achieved at 4:00:30 p.m., EDT, stabilizing the spacecraft on two axes with the third axis on roll inertial control. Sun acquisition came nearly 3-1/2 hours after initiation of the sun search command; the search was scheduled to take only five minutes.

Other Subsystems

Most of the science instruments have been turned on and are transmitting data, indicating they are in good condition. These are the magnetometer, plasma, photopolarimeter, low energy charged particle, planetary radio astronomy, and plasma wave subsystems. Several other instruments are expected to be turned on within the next few days.

The radioisotope thermoelectric generator (RTG) boom, magnetometer boom, and the two planetary radio astronomy and plasma wave antennae deployed normally.

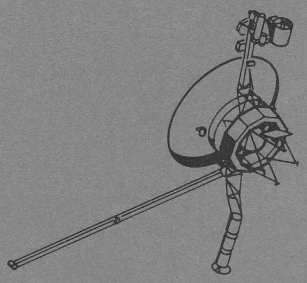
The near-earth testing and calibration of the science instruments scheduled for the first days of the flight may be cancelled for Voyager 2 due to the other problems.

VGR77-2 (Voyager 1)

VGR77-2 will be de-encapsulated on August 22 for inspection of the science boom. This will move the second launch date to September 3.

Three spacecraft were built for the Voyager mission. One, VGR77-1, was designated the Proof Test Model (PTM) and subjected to extensive testing in simulated deep space conditions to test the spacecraft design, construction, and durability. VGR77-2 and -3 were designated flight spacecraft and subjected to less arduous testing to save them for the real deep space conditions. VGR77-3 became Voyager 2 at lift-off on August 20.

Engineers have conducted several tests on the mechanical configuration of the VGR77-1 science boom, including torque tests on the microswitch and stiffness tests of the boom to determine the scan platform settling times at various degrees of deployment.



MISSION STATUS BULLETIN

VOYAGER

August 25, 1977 **No. 4**

CURRENT STATUS

Voyager 2

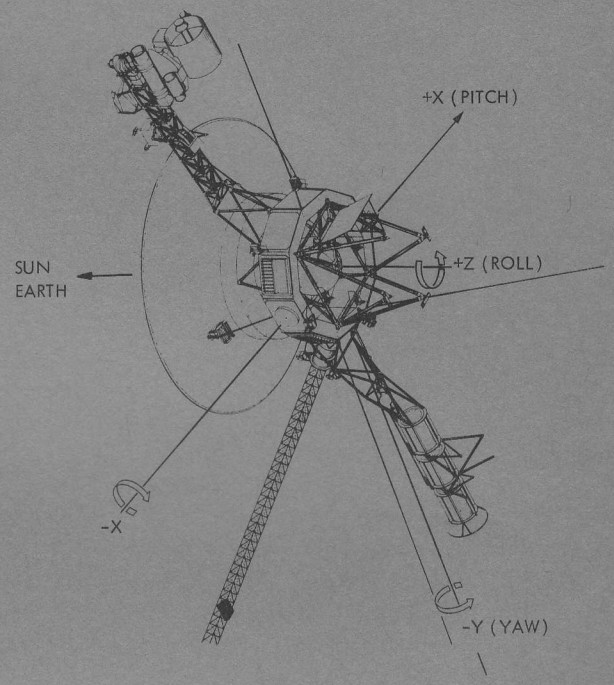
Voyager 2 is now in celestial cruise, after acquiring the star Canopus on August 24. The spacecraft is now stabilized on three axes in celestial lock.

The attitude and articulation control subsystem (AACS) acquires Canopus through a series of roll turns during which the Canopus star tracker assembly of the AACS scans the sky for a light source of the intensity of Canopus and at the proper cone angle. The star is then maintained in the sensor's field of view by actuation of the thrusters.

A specially designed exercise will be conducted early on August 26 to accurately determine the position of the science boom, and to make a concentrated attempt to lock the boom in place, if it is not already there. The attempt-to-lock sequence will involve simultaneously jettisoning the infrared interferometer spectrometer (IRIS) dust cover and rotating the spacecraft in a manner which will put as much torque as possible on the boom in a direction to latch it. The boom angle measurement will involve taking a series of wide-angle TV images of star fields at selected scan platform and spacecraft roll positions.

The first of eight trajectory correction maneuvers (TCMs) planned for the mission will be commanded on August 28. The first maneuver will be commanded in two parts, one part August 28, and the second about 54 days into the flight, during the first week of October. Three more maneuvers will be executed prior to Jupiter encounter and four more between Jupiter and Saturn. Exercise of the Uranus option after Saturn will require another trajectory correction maneuver.

At 11:25 p.m., PDT, August 24, the spacecraft experienced another attitude disturbance similar to the one noted on August 21 at 2:42 a.m., PDT, about 18 hours after liftoff. Flight controllers are analyzing data tapes of the disturbances and have ruled out the possibility that the expended propulsion module may have bumped the spacecraft or that it may still be in the vicinity of the spacecraft.



PITCH, ROLL, AND YAW AXES

VGR77-2 (Voyager 1)

Inspection of the VGR77-2 spacecraft continues at the Spacecraft Assembly and Encapsulation Facility No. 1 (SAEF 1) at Kennedy Space Center. Proper operation of the microswitch on the science boom of this spacecraft has been validated through the Flight Data Subsystem.

Re-encapsulation in the Centaur standard shroud is planned for August 26 with mating to the Titan III E/Centaur launch vehicle at launch complex 41 and power turn-on scheduled for August 28, in preparation for liftoff on September 3.

TC-6 Launch Vehicle

The TC-6 Titan III E/Centaur launch vehicle was moved to launch complex 41 on August 21 and is undergoing preparation for mating with VGR77-2. Launch complex 41 suffered only minimal damage during the launch of Voyager 2 on August 20.

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LAUNCH VEHICLE DESCRIPTION

The Titan/Centaur launch vehicles boosting the Voyager spacecraft toward the outer planets consist of a Titan III E booster, a Centaur upper stage, and a Centaur standard shroud. Voyager 2 rode TC-7, while Voyager 1 will ride TC-6.

The Titan III E booster vehicle consists of two five-segment solid rockets (Stage 0) manufactured by the Chemical Systems Division of United Technologies and the Titan Stage I and II liquid propellant core sections built by Martin Marietta.

The solid rocket propellant is a baked mixture of an oxidizer, ammonium perchlorate, and a fuel, powdered aluminum. The segments initially develop a combined thrust of about 5.34 million Newtons (1.2 million pounds).

The liquid propellant of Stages I and II is Aerozine-50, a 50-50 mix of hydrazine and unsymmetrical dimethylhydrazine (UDMH) oxidized by nitrogen tetroxide. Stage I develops a thrust of 2 million Newtons (470,000 pounds) while Stage II's thrust is 445,000 Newtons (100,000 pounds).

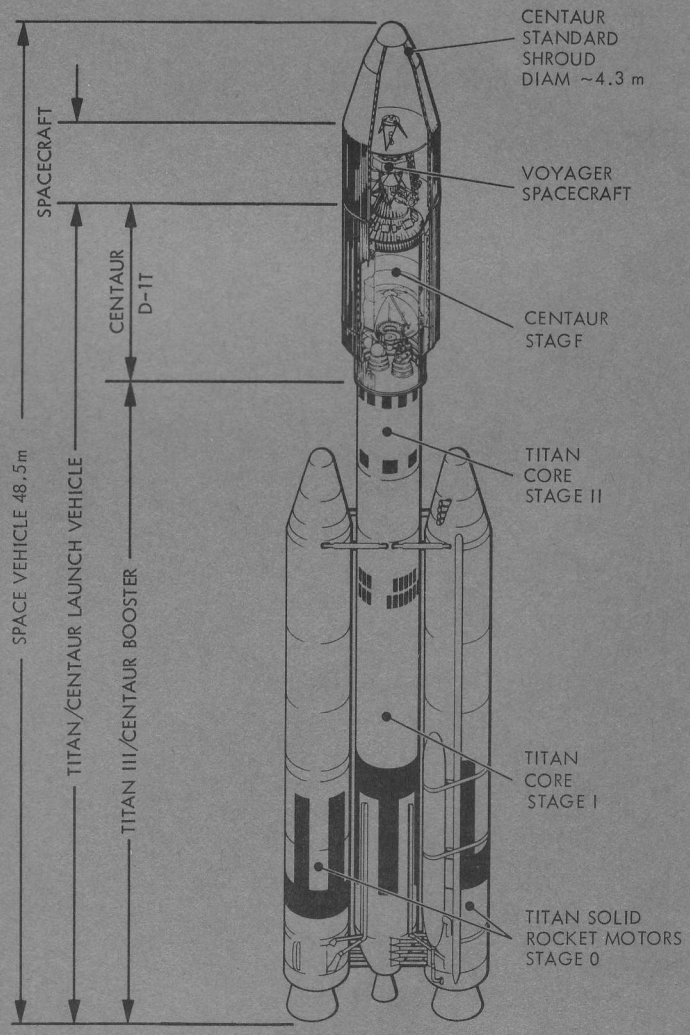
The Centaur prime contractor is General Dynamics/ Convair. The Centaur D-1TR system provides guidance for the entire vehicle, except that the Titan has its own stabilization system. Liquid hydrogen and liquid oxygen propellants are pumped to the two main engines, where a combined thrust of 133,440 Newtons (30,000 pounds) is developed.

The solid rocket motors are seven stories high, while the Titan Stage I and II combination which sits between them rises eight stories. The Centaur stage adds another three stories. With the encapsulated spacecraft (mission module and propulsion module) mated to the Centaur, the entire space vehicle stands 13 stories or 48.5 meters (159 feet).

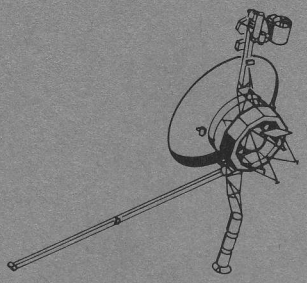
The launch profiles for each Voyager require six separate engine burns, five by the launch vehicle and one by the Voyager propulsion module. Each stage is discarded after completing its burn. The Centaur's first burn injects the Centaur and its payload into a low altitude parking orbit of the earth, and about 51 minutes later the Centaur separates from the Voyager after a second burn. The final boost to Jupiter is provided by the propulsion module.

The propulsion module provides the final boost needed for spacecraft injection into a Jupiter trajectory. The solid rocket motor in the propulsion module ignites about 15 seconds after the spacecraft separates from the Centaur stage. It burns for approximately 45 seconds and is jettisoned about 11 minutes later. Four pyrotechnic squibs explode to release the propulsion module from the mission module. The distance between the propulsion and mission modules nominally increases at a rate of about 0.61 meter (2 feet) per second due to the spring separation impulse.

The propulsion module is basically an aluminum cylinder, 99 cm (39 inches) in diameter and 89 cm (35 inches) long, suspended below the mission module by a tubular truss adapter. The rocket carries 1,039 kg (2,290 pounds) of hydrazine propellant, developing an average 68,085 Newtons (15,300 pounds) thrust and adding a velocity increment of about two kilometers per second (4,475 miles per hour).



TITAN III E/CENTAUR/VOYAGER SPACE VEHICLE



MISSION STATUS BULLETIN

VOYAGER

August 29, 1977 **No. 5**

STATUS SUMMARY

Voyager 2 is about 8 million kilometers (5 million miles) from earth, cruising at 10 kilometers per second (22,370 miles per hour). Calibration of the sun sensors and deployment of the dust cover on the infrared interferometer spectrometer (IRIS) instrument was accomplished the morning of August 29.

Voyager 1 launch is set for September 5 at 5:56 a.m., PDT. The spacecraft will be reencapsulated in the Centaur shroud on August 29.

CURRENT STATUS

Voyager 2

It is still not certain that the science boom aboard Voyager 2 is latched, but star maps returned by the wide-angle cameras indicated that the hinge is only fractions of a degree away from being locked and should present no problems in maneuvering the boom.

The boom is stiff enough to prevent wobbling when the scan platform perched at its tip is maneuvered, and should stiffen further as the spacecraft travels farther from the sun into the colder regions of deep space.

Voyager 2 returned three images along the edge of the science calibration plate on August 26 and 10 star field images on August 27, during sequences designed to more precisely measure the deployment angle of the science boom. From these images, it appears that the hinge is within 0.06 degree of the locked position.

A sequence commanded the morning of August 26 in an effort to move the boom to the locked position was aborted by the computer command subsystem when the attitude and articulation control subsystem (AACS) computer falsely indicated that it might have a problem. The spacecraft is programmed to abort the current sequence and return to celestial lock whenever a significant problem is indicated.

On August 26 the spacecraft generated three images before returning to celestial lock. In this sequence, the spacecraft was removed from its lock on the sun and Canopus in order to execute a pitch turn. It was hoped that simultaneously pitching the spacecraft and jettisoning the dust cover on the infrared interferometer spectrometer (IRIS) by means of small explosive devices would provide enough of a jolt to fully open the boom hinge and allow the locking pin to drop into position. However, the sequence was aborted before this series of events, and the spacecraft automatically restabilized itself by reacquiring the sun and Canopus.

The first trajectory correction maneuver and X-band radio transmitter calibrations have been deferred to a later opportunity, to allow flight controllers to concentrate on the more immediate needs of Voyager 2 and the launch of VGR77-2.

All but one of the science instruments have been turned on. The ultraviolet spectrometer (UVS) may be turned on during the September 2 sequence.

Temperature readings aboard the spacecraft were high on August 29 as the spacecraft made its closest approach to the sun. Engineers monitored the temperatures but found no cause for concern.

VGR77-2 (Voyager 1)

VGR77-2 will be launched on September 5 at 8:56 a.m., EDT (5:56 a.m., PDT) from launch complex 41, Air Force Eastern Test Range, Cape Canaveral, Florida. A launch readiness review will be conducted on August 31 and September 1 at Cape Canaveral.

Engineers have installed five coil springs on the science boom of VGR77-2 to assure proper deployment and locking.

The Centaur shroud will be lowered over the spacecraft on August 29, and post-encapsulation electrical tests will be conducted in preparation for mating to the TC-6 launch vehicle at launch complex 41.

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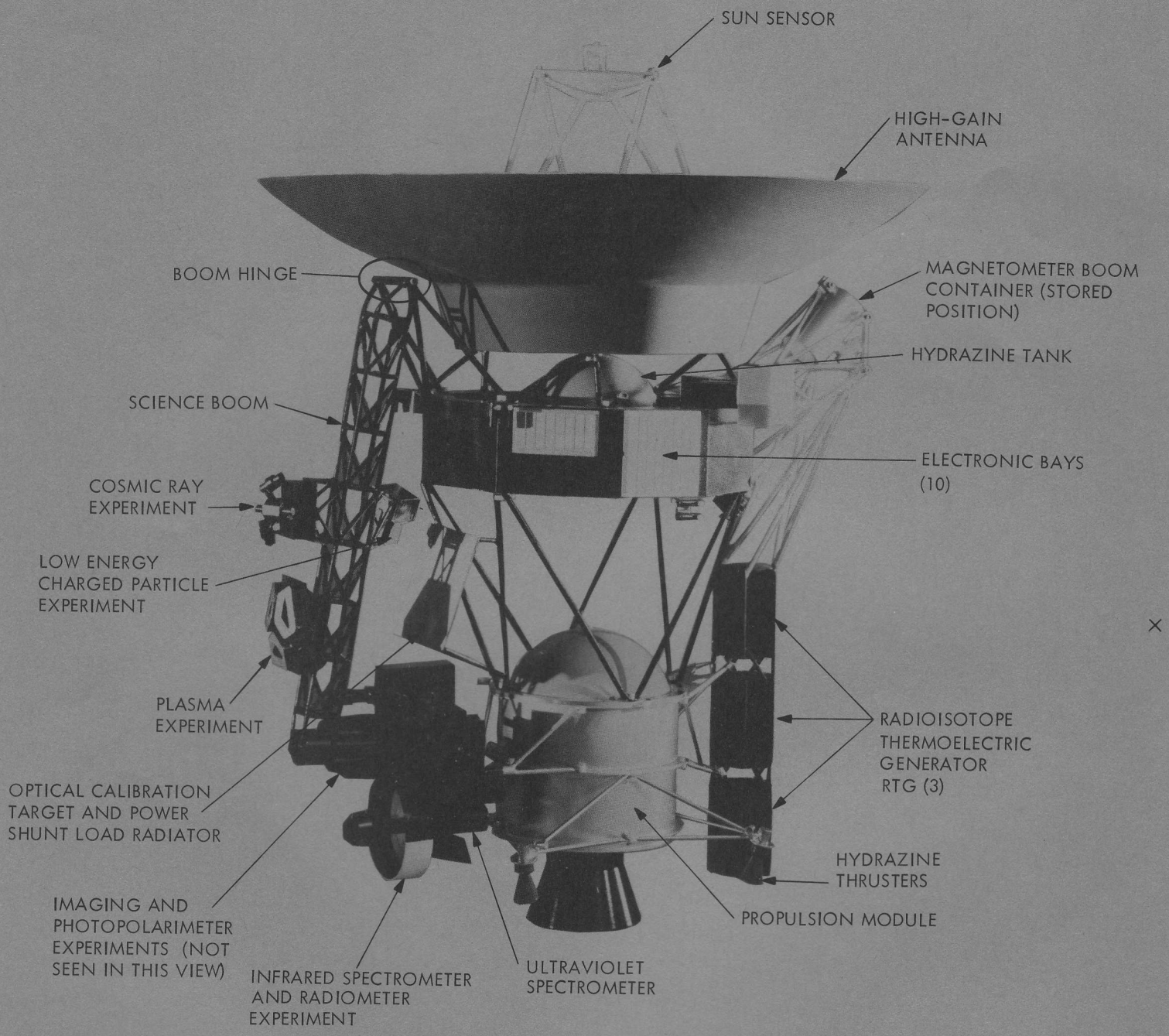
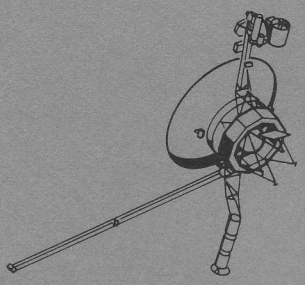


Voyager Spacecraft in Stowed Position

Voyager is encapsulated in the Centaur shroud with its booms and antennas stowed in this manner. The shroud is discarded about four minutes after launch, and 49 minutes later, after the final boost to Jupiter, boom deployment begins.



MISSION STATUS BULLETIN

VOYAGER

September 1, 1977 **No. 6**

CURRENT STATUS

VGR77-2 (Voyager 1)

Final preparations are proceeding for the launch of VGR77-2 (Voyager 1) on Labor Day, September 5. VGR77-2 was re-encapsulated in the Centaur standard shroud on August 29 and moved to launch complex 41 August 31 for mating with the Centaur. A practice countdown will be held September 2.

The launch window opens at 5:56 a.m., PDT, on Labor Day. Voyager 1, as did Voyager 2, will reach a low altitude earth parking orbit before the propulsion module gives it its final boost out of the earth's gravity on a trajectory for Jupiter.

Voyager 1 will fly a faster trajectory than Voyager 2, arriving at Jupiter four months in advance of its sister ship. Voyager 1's Jupiter observatory activities will begin about December 15, 1978, more than 16 months after launch. Closest approach to Jupiter will be about March 5, 1979, at a distance of 286,000 kilometers (178,000 miles) from the visible surface of the planet.

On its outbound leg, Voyager 1 will study five of Jupiter's 13 or 14 known satellites – Amalthea, Io, Ganymede, Europa, and Callisto. Voyager 1 will also pass through the Io flux tube – a region of high magnetic and plasma interaction between Jupiter and Io. At Jupiter, Voyager 1 will be 4.6 astronomical units (AU) (1 AU = 150,000,000 kilometers or 93,000,000 miles) from earth; radio signals between earth and the craft will take 38 minutes each way.

At Saturn, Voyager 1 will pass within 4,000 kilometers (2,500 miles) of Titan, a Saturnian satellite of immense interest. Saturn observations will begin in August 1980, with closest approach to the planet about November 13, 1980. Voyager 1 will pass about 138,000 kilometers (85,800 miles) from Saturn's south pole, and its radio signals will trickle through the rings, giving clues as to their composition. At a distance of 10.2 AU, one-way communication time with the spacecraft will be 85 minutes. Voyager 1 will also study the satellites Mimas, Dione, Enceladus, Tethys, and Rhea, in addition to the close Titan pass. After Saturn, Voyager 1 will cruise out of the solar system.

LAUNCH DAY ACTIVITIES

All JPL employees, contractors, and their families are invited to participate in the Voyager launch activities Labor Day, Monday, September 5. Launch is scheduled for 5:56 a.m., PDT, and the Laboratory facilities will open at 5:00 a.m.

Launch activities will be presented via live audio from Cape Canaveral, Florida. There will be two seating areas available: von Karman Auditorium (Bldg. 186) and the 180-101 conference room. Parking will be available in the visitor and adjacent parking lots. The main cafeteria will be serving from 4:00 a.m. to 1:30 p.m.

Launch events commentary from Kennedy Space Center will be broadcast from approximately 5:30 a.m. to 7:00 a.m., PDT. Spacecraft events will be televised from JPL from approximately 7:00 a.m. to 10:00 a.m., PDT.

Voyager 2

Voyager 2 is in interplanetary cruise, and on September 2, will be "put to bed" to allow flight controllers to concentrate on the second launch. The computer program to be transmitted to the craft on September 2 is a "housekeeping" sequence designed to automate the ship until about launch plus 30 days, around September 20. Various measurements will be taken during this period, and tape recorded for later playback at earth.

All but one of the science instruments have been turned on. A brief status report on each science instrument subsystem follows:

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Cosmic Ray Subsystem (CRS). On and operating well. Temperatures near perihelion day (closest approach to the sun, August 29) were slightly above flight acceptance test limits (20°C), but the instrument is capable of operating well above this limit and there is no concern.

Imaging Science Subsystem (ISS). On to perform selected sequences and operating well. The wide-angle cameras have returned images of the spacecraft calibration plate and star fields to aid in more accurately determining the science boom alignment. Wide-angle images of the earth and moon are planned for September 2, but will be tape recorded for later playback.

Infrared Interferometer Spectrometer (IRIS). The dust cover has been deployed and the instrument is working well. The instrument does not normally gather data during the cruise mode; the only activity planned is a deep space calibration as the instrument is thermally stabilized.

Low-Energy Charged Particles (LECP). On and operating well. The stepper motor appears to have slipped one position, but this should cause no long-term problems in operation of the experiment.

Magnetometer (MAG). On and operating well. The two low-field magnetometers spaced at the tip and mid-way point on the magnetometer boom are aligned within about 2 degrees.

Photopolarimeter Subsystem (PPS). On and operating normally except for a slight irregularity in analyzer wheel stepping. Tests to analyze the stepping will be conducted during the housekeeping period in September and will be tape recorded for later playback at earth.

Planetary Radio Astronomy (PRA). On and operating well. In the first days of the flight, plasma subsystem measurements gave the first indication that the science boom was nearly fully deployed.

Plasma Subsystem (PLS). On and operating well.

Plasma Wave Subsystem (PWS). On and operating normally. The spacecraft noise is as quiet or quieter than expected at the lower frequencies monitored by the instrument.

Radio Science Subsystem (RSS). The S-band radio transmitter is on and working well; the X-band transmitter has not been turned on yet.

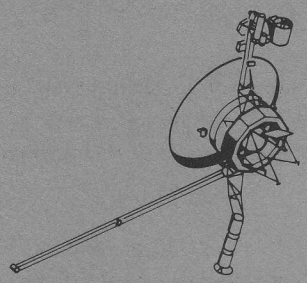
Ultraviolet Spectrometer (UVS). The ultraviolet spectrometer will be turned on September 2.

VOYAGER SELECTED TRAJECTORY INFORMATION (TYPICAL)

Events	Time	Surface Range		Altitude	
	(hr:min:sec)	(kilometers)	(nautical miles)	(kilometers)	(nautical miles)
Launch - Solid Rocket Motors (SRMs) Ignition	00:00:00	0	0	0	0
SRMs Burnout and Core Stage I Ignition	00:01:51	43	23	41	22
SRMs Jettison	00:02:02	57	31	46	25
Core Stage I Shutdown & Separation; Core Stage II Ignition	00:04:15	396	214	113	61
Jettison Shroud	00:04:26	437	236	119	64
Core Stage II Shutdown	00:07:44	1,446	781	167	90
Core Stage II Separation	00:07:50	1,541	832	167	90
Centaur Main Engine Start (MES) 1*	00:08:01	1,552	838	169	91
Centaur Main Engine Cutoff (MECO) 1	00:09:44	2,189	1,182	169	91
Centaur MES 2	00:52:45	19,315	10,429	157	85
Centaur MECO 2	00:58:22	15,918	8,595	335	181
Centaur Separation	01:01:12	14,225	7,681	911	492
Voyager Propulsion Module Ignition	01:01:27	14,075	7,600	980	529
Voyager Propulsion Module Burnout	01:02:12	13,610	7,349	1,219	658
Propulsion Module Separation	01:13:29	9,493	5,126	7,414	4,003

*Injection into parking orbit.

NOTE: These times and distances may vary, depending on the exact launch day, launch time, and spacecraft weight.



MISSION STATUS BULLETIN

VOYAGER

September 5, 1977 **No. 7**

STATUS SUMMARY

Voyager 1 is in celestial cruise, and, twelve hours after launch, was about 430,000 kilometers (267,000 miles) from Earth, having passed the Moon two hours earlier at a distance from the surface of 92,000 kilometers (57,000 miles).

Voyager 1 is locked on both the Sun and its reference star Canopus, stabilized on three axes, and returning good data. All of the booms and antennas have deployed normally and are locked into position. All of the science instruments scheduled for turn-on at this point are on and operating well, except for the photopolarimeter which has been turned off to protect it from an undesirably high level of reflective light from the Moon ("moon shine").

Voyager 2 continues in its quiescent state, over 14 million kilometers (8½ million miles) from Earth. Real-time science commands will be sent at predefined opportunities during the quiet period. The photopolarimeter instrument has been turned off.

CURRENT STATUS

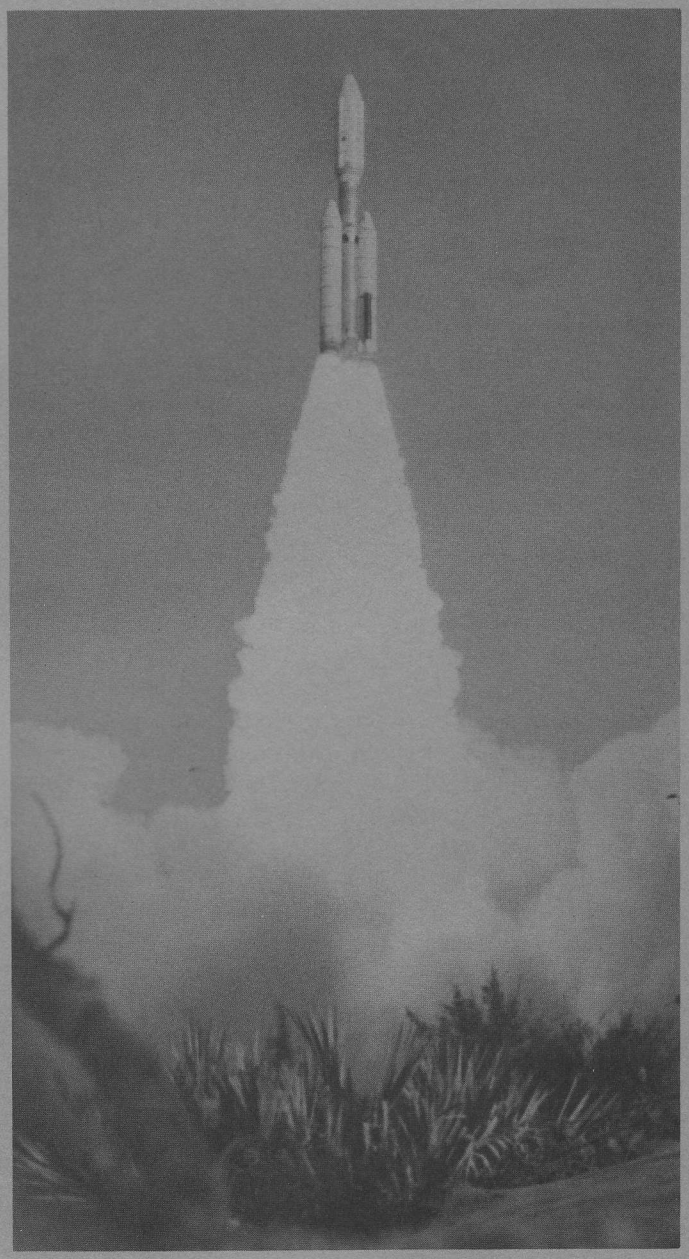
Voyager 1

Voyager 1, aboard a Titan III E/Centaur launch vehicle, lifted off launch complex 41 at the Air Force Eastern Test Range (AFETR), Cape Canaveral, Florida, at 8:56:01 a.m., EDT (5:56:01 a.m., PDT), September 5, 1977, sixteen days after its twin. The launch countdown went smoothly with no unscheduled holds.

Voyager 1's computing systems are operating well, with none of the attitude control problems encountered during the launch of Voyager 2. A switch to a secondary thruster system was noted during the magnetometer boom deployment; a reset to initial conditions was commanded about 12 hours after launch.

The sequence of events aboard the spacecraft following insertion into Earth orbit occurred according to schedule, with release and lock of the radioisotope thermoelectric generator, science, and magnetometer booms occurring about one hour after launch and deployment of the planetary radio astronomy and plasma wave subsystem antenna about an hour later.

VOYAGER 1: SEPTEMBER 5, 1977 8:56:01 a.m., EDT



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The spacecraft was stabilized on two axes about two hours into the flight when the sensors acquired the Sun, and achieved three-axis stabilization with Canopus acquisition several hours later.

During the launch phase, the launch vehicle's Titan Stage II burned for a shorter period than planned, necessitating a longer first burn by the Centaur stage. The first burn of the Centaur stage used about 545 kilograms (1200 pounds) more fuel than planned. The second Centaur burn, just prior to injection into the Jupiter trajectory, was shorter due to its lighter fuel load, and burned about 140 kilograms (310 pounds) more fuel than planned.

The effect of the short Titan burn is under study, but appears to have had no effect on the desired trajectory.

The final Jupiter trajectory insertion boost of the propulsion module provided a bonus by requiring less than 2 kilograms (4½ pounds) of hydrazine of an allotted 14 kilograms (31 pounds). This fuel-savings was also noted in Voyager 2 on August 20, giving both spacecraft an extra measure of fuel for attitude control.

The launch of Voyager 1 marks the last planned use of the Titan III E/Centaur launch vehicle, a combination which has completed six successful launches, including both of the Viking spacecraft to Mars and Voyager 2.

Voyager 1 carries a duplicate of the copper-plated, aluminum-jacketed "Sounds of Earth" recording carried by Voyager 2. Included with the 12-inch disc is a cartridge and needle, and instructions on how to play the record. In addition to greetings in 60 human languages, a sound essay on the evolution of our planet, and a selection of music, the record includes data which can be reconstructed to form 115 photographs and diagrams, 20 of which are in color. The idea of the records is somewhat like tossing a note in a bottle into the ocean – in this case, a cosmic ocean.

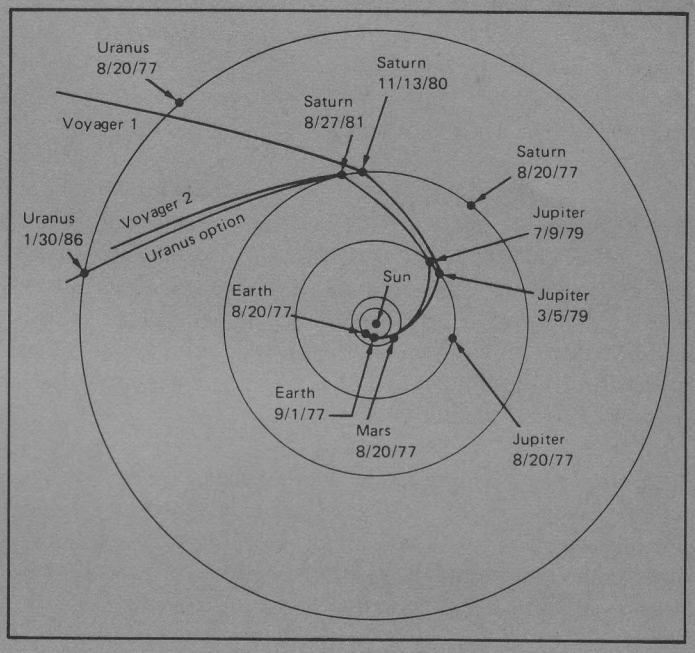
Although launched 16 days after its twin, Voyager 1, due to the alignment of the planets at the time of the launch, will fly a faster trajectory relative to the Sun and will arrive at Jupiter four months ahead of Voyager 2, beginning its observations in mid-December, 1978. Voyager 1 will travel a total of 998 million kilometers (620 million miles) to Jupiter.

Voyager 2

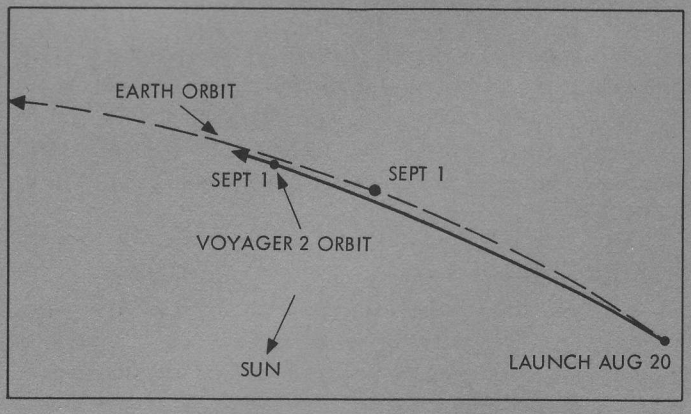
Voyager 2 is in a quiet mode, with little activity planned until about September 20 except for occasional science commands.

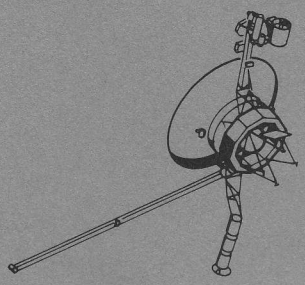
The photopolarimeter instrument has been turned off due to the sticking of the analyzer wheel. The instrument will remain off to protect it from the Sun's rays until the problem can be analyzed and corrected.

Voyager 2 will travel a total of 1.2 billion kilometers (699 million miles) to Jupiter, beginning its observations in April, 1979, 20 months after launch.



VOYAGER TRAJECTORIES. The Voyager spacecraft will "chase" after the outer planets, as all orbit the Sun. The trajectory plot above, looking down from a point above the Sun's north pole, shows the position of the planets at the time of Voyager 2 launch, August 20, 1977. Voyager 1 dates will be slightly later due to the 4-day launch slip from the original schedule. Voyager 2 began its journey by travelling between the Sun and the Earth's orbit (see insert below) but soon sped away from the warmer regions near the Sun into colder deep space.





MISSION STATUS BULLETIN

VOYAGER

September 14, 1977 **No. 8**

CURRENT STATUS

Voyager 1

Voyager 1, launched September 5, completed its first trajectory correction maneuver in two parts on September 11 and 13.

Both maneuvers included calibration sequences of the dual frequency communications links, the high-gain antenna S- and X-bands. During these sequences, the 3.7-meter (12-foot) diameter high-gain antenna dish is pointed towards Earth and the S-band (about 2295 megahertz) and X-band (about 8418 megahertz) radio links are calibrated. Except for this calibration sequence, the X-band will not be in use during about the first 80 days of the mission. Communications during launch, near-Earth and early cruise phase operations are confined to S-band and the low-gain antenna.

The radio calibrations were performed while the spacecraft was transmitting to the Goldstone Deep Space Station near Barstow, California. Only the large 64-meter (210-foot) dish antenna stations of the Deep Space Network can receive the X-band signal. Both the 64-meter and 26-meter (85-foot) dish antenna stations are capable of receiving at the lower-rate S-band.

During the September 13 sequence, the scan platform was pointed at deep space and the ultraviolet spectrometer (UVS) instrument was turned on.

The infrared interferometer spectrometer (IRIS) dust cover was deployed on September 13 and the instrument is operating properly.

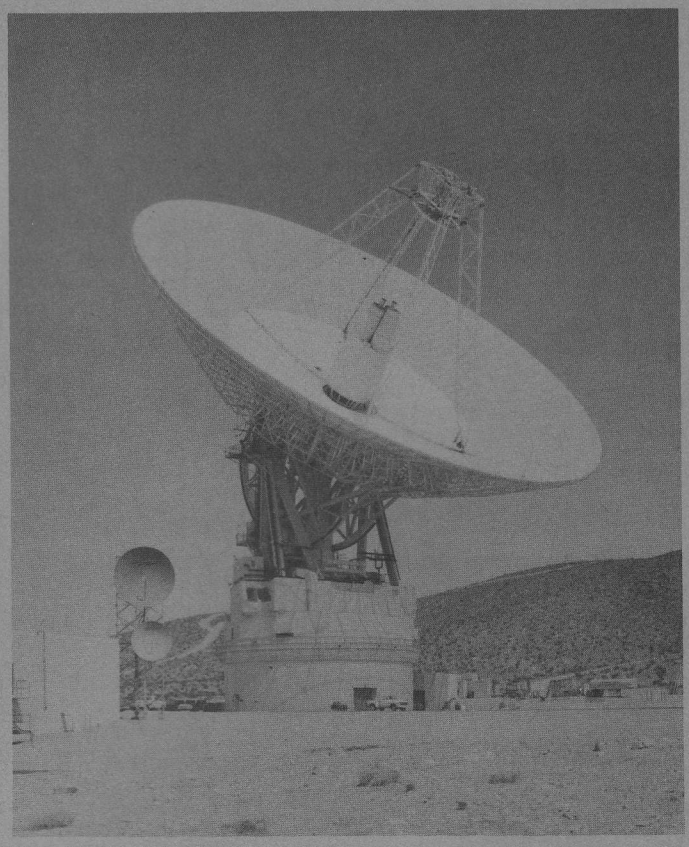
Voyager 1 will begin cruise mode on September 15, having completed all planned near-Earth activities. A recorded Earth-Moon video and optical navigation data sequence is planned for September 16, with playback at a later date.

Voyager 2

Voyager 2, launched August 20, continues in cruise mode with real-time science commands being uplinked (sent to the spacecraft from Earth via S-band) at pre-determined opportunities.

A fields and particles instruments calibration sequence was performed on September 12. On September 16, the infrared interferometer spectrometer (IRIS) instrument will perform deep space calibrations, and a diagnostic sequence will be performed on the photopolarimeter (PPS) analyzer wheel.

Voyager 2's first trajectory correction maneuver is planned for early October, 54 days after launch.



TRACKING. The 64-meter (210-foot) antenna at Goldstone, near Barstow, California, is part of the Deep Space Network tracking system.

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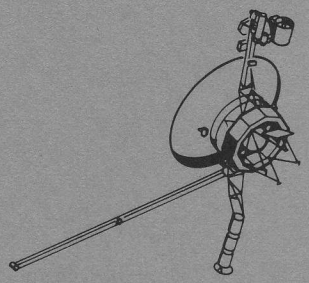

MISSION STATUS BULLETIN

VOYAGER

September 29, 1977 **No. 9**

SUMMARY

Twenty-four days after launch, Voyager 1 is 21 million kilometers (13 million miles) from Earth, cruising at a velocity of 35,470 kilometers (22,040 miles) per hour. One-way communication time with the spacecraft is 68 seconds. Science calibration and configuration commands are being uplinked during real-time command windows.

Voyager 2, now forty days into its journey towards Jupiter, Saturn, and possibly Uranus, is 33 million kilometers (20 million miles) from Earth, cruising at a velocity of 30,520 kilometers per hour. One-way communication time with the spacecraft is 1 minute 47 seconds. Science calibration and configuration commands are being uplinked during real-time command windows, and a tree switch (circuitry) failure in the flight data subsystem (FDS) is being analyzed.

UPDATE

VOYAGER 1

Trajectory Correction Maneuver

Voyager 1's first trajectory correction maneuver (TCM) was accomplished in two parts September 11 and 13; real-time data was received during the first of the thruster burns.

Analysis of the TCM data indicates a 20 percent undervelocity resulting from each part of the maneuver. The suspected cause is impingement of the thruster exhaust on spacecraft structural support struts. Part one of the maneuver increased the craft's velocity by 2.45 meters per second, the second by 10.11 meters per second. The ungained velocity will be compensated for during the next scheduled trajectory correction maneuver.

These periodic flight path adjustments are necessary to assure precise arrival times of the spacecraft at their objectives, to maximize science data return. In the case of Voyager 1, its exact arrival (closest approach) at Jupiter (March 5, 1979) is crucial to studying the interaction between Jupiter and its satellite Io.

Video Playback

Optical navigation data and an Earth-Moon video sequence recorded on September 18 will be played back on October 7 and 10, as currently scheduled. The playback sequence requires pointing the high-gain antenna toward Earth, and must be done in two parts to protect temperature-sensitive portions of the spacecraft from the colder temperatures of space, since some areas of the craft are temporarily shaded from the Sun's rays during the Earth-point maneuver.

The video sequence of the Earth-Moon system includes pictures taken at 18 different pointing positions, photographed with each of three color filters to allow construction of composite color photographs.

Science Instruments

The science instruments aboard Voyager 1 are in good health and operating as planned. The photopolarimeter data is being analyzed to better understand the nature of a high photon count indicating a bright light source in a position where none is known to exist.

VOYAGER 2

FDS Tree Switch

On September 23, Voyager 2 experienced a failure in the flight data subsystem (FDS) circuitry which has resulted in the loss of 15 of 243 engineering measurements which can be sent to Earth. The loss could be permanent if due to an integrated circuit failure, or possibly temporary if due to an electronic latch switching condition. Problem isolation is in progress, and an unlatching attempt is being designed.

Of the 15 measurements, several are duplicated in the remaining 228 measurements, a few can be deduced from combinations of other measurements, others were needed only during launch, and the remainder may have some effect on performance analysis of other subsystems aboard the spacecraft.

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Trajectory Correction Maneuver

Voyager 2's first trajectory correction maneuver is scheduled for October 11. Current estimates of the hydrazine fuel budget indicate there is sufficient fuel to support the mission through a Uranus encounter in 1986, despite the gas utilization problems to date.

Science Instruments

Science commands are being sent to Voyager 2 during regularly scheduled real-time command windows. Recent commands have included calibrations of the magnetometers and the fields and particles instruments. One of these magnetometer calibration sequences creates a magnetic field around the spacecraft by periodically powering a wire which runs the circumference of the high-gain antenna dish.

The photopolarimeter instrument has been turned off. After being freed once, the analyzer wheel is currently stuck again in a safe position, and the problem is being analyzed.

TRACKING AND DATA ACQUISITION

From the moment of launch, the Voyager spacecraft have been under constant surveillance by a world-wide tracking and data system which includes elements of the NASA/Jet Propulsion Laboratory Deep Space Network (DSN), the Air Force Eastern Test Range (AFETR), and the NASA Spaceflight Tracking and Data Network (STDN).

Near-Earth Facilities

From launch through the propulsion module burn which boosted the spacecraft into their Jupiter-bound trajectories, tracking and data acquisition was accomplished by the near-Earth facilities, including the AFETR stations downrange elements of the STDN, ARIA jets (Advanced Range Instrumented Aircraft), and a communications ship at sea, the U.S.N.S. Vanguard.

Tying together all NASA sites is the NASA Communications Network (NASCOM). Voice and data communications flow through its three million circuit miles of electronic circuitry and two mid-ocean satellites.

Deep Space Network

Tracking and communication with the Voyagers from injection into the Jupiter trajectories, about one hour after launch, until the end of the mission, is conducted by the Deep Space Network (DSN).

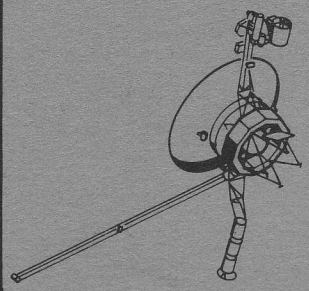
The DSN consists of nine deep space communications stations on three continents, the Network Operations Control Center in the Mission Control and Computing Center at the Jet Propulsion Laboratory in California, and NASCOM-provided ground communications linking all locations.

Each DSN location – at Goldstone, California; Madrid, Spain; and Canberra, Australia – has one 64-meter (210-foot) diameter antenna and two 26-meter (85-foot) diameter antennas.

The three multi-station complexes are strategically located at widely separated global longitudes so that spacecraft beyond Earth orbit – and, for the Voyager mission, the planets Jupiter and Saturn – are seldom if ever out of "view" as all move through space. As the spacecraft move farther from Earth, they will always be in view, but near Earth, there is a short daily gap in Voyager 2 tracking data between the Australian and Spanish stations.

Data transmitted from the spacecraft, the downlink, is sent at S-band (2295 megaHertz) and X-band (8400 megaHertz) radio frequencies. Commands and ranging signals sent from Earth to the spacecraft, the uplink, are transmitted at S-band (2113 megaHertz) only.

DEEP SPACE NETWORK STATIONS



MISSION STATUS BULLETIN

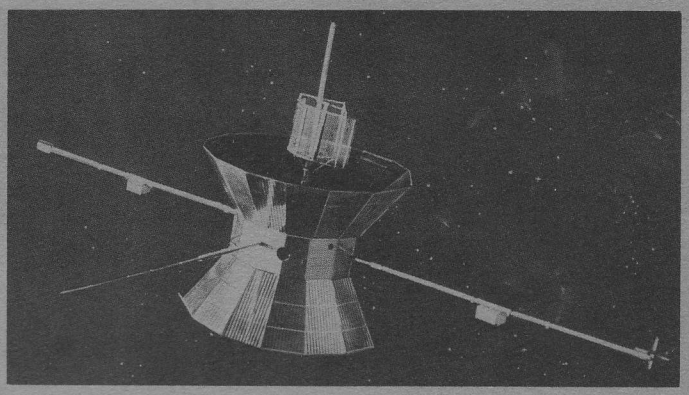
VOYAGER

October 20, 1977 No. 10

SUMMARY

Voyager 1 is 39 million kilometers (24.5 million miles) from Earth, cruising at a velocity of 40,190 kilometers (24,975 miles) per hour, forty-five days after launch. One-way communication time is 2 minutes 11 seconds.

Sixty-one days after launch, Voyager 2 is still ahead of its pursuing companion ship, 48 million kilometers (30 million miles) from Earth, traveling at 34,870 kilometers (21,670 miles) per hour. One-way communication with the craft now takes 2 minutes 40 seconds.



HELIOS. Helios and Voyager will cooperate to gather solar-related data during the latter part of 1977.

MISSION HIGHLIGHTS

Comet Kohler Observation Opportunity

In the latter part of this year, the Voyagers will have the opportunity to study the recently detected comet, Kohler.

Kohler appears to be in a hyperbolic orbit inclined about 49° from the ecliptic plane. Its closest approach to Voyager 1 is expected to be November 8 at a distance of 1.28 AU (1 AU = 150 million kilometers or 93 million miles), and to Voyager 2 on November 10 at 1.25 AU. The comet will pass closer to Earth, about 1 AU, on November 10, but better scientific measurements and longer study times will be obtained from the spacecraft.

Hydrazine Conservation Studies

Both spacecraft are consuming more propellant than predicted. The causes include trajectory correction maneuver (TCM) thruster plume impingement, solar pressure effects reaction to digital tape recorder start/stop, and scan platform motion. Studies are underway to determine propellant needs for the duration of the mission versus that available, and to determine what conservation measures are possible.

Preliminary estimates show that neither the primary Jupiter/Saturn mission nor the Uranus option is jeopardized.

Voyager-Helios Cooperation

Voyager and Helios, a German-managed spacecraft project which studies the area between the Sun and the Earth, will join in international cooperation to take advantage of a unique radial alignment of the Sun, the Helios spacecraft, the Earth, and the Voyager spacecraft to obtain data on solar-related fields and particles phenomena.

During the period between October 15 and late December, 1977, the 30-meter antenna at Weilheim, Germany, will track the Voyager spacecraft as often as once a day.

Helios 1 was launched on December 10, 1974 and Helios 2 on January 15, 1976, both from Cape Canaveral, Florida aboard Titan IIIE/Centaur launch vehicles similar to those which boosted the Voyagers aloft this fall. Both Helios spacecraft orbit the Sun, passing as close as 1/3 AU and continuously gathering scientific data.

Visit by Prince Charles

Prince Charles, heir to the throne of Britain, will visit Mission Operations at the Jet Propulsion Laboratory on October 27. The prince, an accomplished pilot, will tour the Laboratory, view Voyager operations, transmit a command to Voyager 2, and communicate with the Australian tracking station.

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SPACECRAFT SUMMARY

VOYAGER 1

Video Playback

On October 7 and 10, most of an Earth-Moon video sequence recorded on September 18 was played back to Earth from Voyager 1's on-board tape recorder. Portions of the sequence have yet to be transmitted to Earth.

The photographs, taken at 18 different pointing positions with three color filters, have been sent to JPL's Image Processing Laboratory for mosaicking and combination of the sets into color composites.

Trajectory Correction Maneuver 2

Voyager 1's second trajectory correction maneuver is scheduled for October 29. This maneuver will compensate for the impingement-caused undervelocity resulting from the first correction on September 11 and 13, as well as correct small expected launch errors.

VOYAGER 2

FDS Tree Switch

An effort to reset the flight data subsystem (FDS) tree switch, which failed September 23, was performed on October 10 and was unsuccessful. The problem is now considered a permanent hardware failure, and "work around" alternatives are under study.

The failure affects 15 separate engineering measurements, an internal FDS measurement, and four redundant measurements.

Trajectory Correction Maneuver 1

Voyager 2's first trajectory correction maneuver (TCM) was performed on October 11, achieving the desired correction within one percent.

In anticipation of experiencing a similar thruster plume impingement to that observed on Voyager 1's first TCM, an overburn and pitch turn adjustment were incorporated into the sequence.

Deneb Acquisition

Plans to roll the Voyager 2 so that the star tracker uses the star Deneb as a reference have been made for October 31. Deneb lies on the opposite side of the spacecraft from Canopus, and acquiring this star will effectively turn the spacecraft upside down. The benefits will be to minimize the effect of the solar pressure which is contributing to the frequent attitude control thruster firings to steady the ship, and to allow an earlier pointing of the high-gain antenna to the Earth.

THE VOYAGER SPACECRAFT

(This is the first in a planned series of brief explanatory notes on the spacecraft and its instruments.)

Part I — The Bus

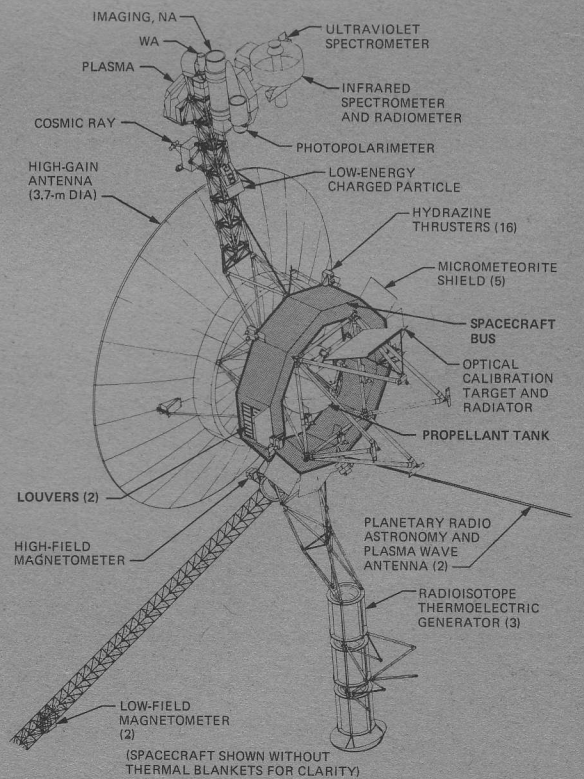
The identical Voyager spacecraft were designed and built by the Jet Propulsion Laboratory (JPL), Pasadena, California, which also designed and built planetary explorers of Mercury, Venus, and Mars, including the Mariners and Viking Orbiters. The design philosophy, taking into consideration the unfriendly environment of space, the long duration of the mission, and the great distances to be traveled, relies heavily on redundancy, reliability, and thermal protection.

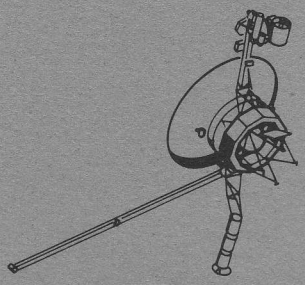
The basic structure of each craft is the bus, a 24.5-kilogram (54-pound) ten-sided aluminum framework ring with ten electronics packaging compartments. The bus is about 45 centimeters (about 1-1/2 feet) high and 179 centimeters (about 6 feet) across.

The bus houses the electronics assemblies, including the three on-board engineering computing subsystems — the flight data subsystem, the computer command subsystem, and the attitude and articulation control subsystem.

Two faces of the decagonal bus contain thermostatically-controlled louvers which regulate the heat radiated from the main equipment compartment. Top and bottom of the structure are enclosed with multilayer thermal blankets.

The propellant tank, which supplies fuel to the hydrazine thrusters for attitude control and trajectory correction maneuvers, occupies the center cavity of the decagon.





MISSION STATUS BULLETIN

VOYAGER

November 7, 1977 **No. 11**

SUMMARY

Voyager 1 is over 59 million kilometers (36 million miles) from Earth, steadily closing the gap between itself and its sister ship. At the speed of light (300,000 kilometers or 186,000 miles per second), one-way communication time is about 3 minutes. The second trajectory correction maneuver was executed on October 29.

Voyager 2 is over 64 million kilometers (40 million miles) from Earth. One-way communication time is about 3-1/2 minutes. At Jupiter, this will stretch to about 38 minutes, and to 85 minutes at Saturn.

In less than a month, both spacecraft will cross the orbit of Mars, half an AU (astronomical unit) beyond Earth. At this point, Voyager 1 will pass Mars from about 139 million kilometers (86 million miles), and Voyager 2 will pass 137 million kilometers (85 million miles) from Mars.

As they leave the realm of the terrestrial planets, headed for the outer planets, the Voyagers will soon be entering the asteroid belt which lies between the orbits of Mars and Jupiter.

UPDATE

Voyager 1

Voyager 1's second trajectory correction maneuver, to "clean-up" small flight path inaccuracies, was executed on October 29. Pointing inaccuracies and undervelocity resulting during the first trajectory maneuver on September 11 and 13 were accounted for in the sequence.

Other recent spacecraft activities have included magnetometer, photopolarimeter, and plasma instrument calibrations, radio frequency subsystem (RFS) tests, and tests of the RFS tracking loop capacitor.

Voyager 2

On October 31, Voyager 2 was rotated to acquire the star Deneb as a celestial reference point. This position will allow earlier Earth-acquisition during high-gain antenna Earth-pointing maneuvers required during playbacks and other sequences.

Studies of the fuel budget and the effect of acquiring Deneb as a gas-savings tactic are continuing.

Voyager 2's first trajectory correction maneuver on October 11 slightly adjusted the aiming point for the Jovian satellite Ganymede. Voyager 2's closest approach to Ganymede is now planned for about 60,000 kilometers (37,000 miles) rather than 55,000 kilometers (34,000 miles) on July 9, 1979.

In addition, the post-Jupiter trajectory correction maneuver to Saturn has been rescheduled for 11 days after Jupiter closest approach (J+11 days) from the previously planned J+70 days. In combination with the Ganymede aiming point adjustment, a total hydrazine savings of approximately 8.6 kilograms (19 pounds) will result.

An apparent failure of the low-energy charged particle (LECP) instrument stepper motor is being investigated.

MISSION HIGHLIGHTS

Comet Kohler

No attempt will be made to observe the comet Kohler, as further studies have determined that damage to the optics of the imaging cameras would be probable.

Observation of the comet would require turning the spacecraft to a position which would place the cameras too near a direct line to the Sun for too long a period, causing probable damage to the vidicons.

Weilheim Tracking

Tracking by the Helios Project at the station in Weilheim, Germany, continues. Studies aimed at improving the data quality are underway. The unique radial alignment of the Sun, Helios, Earth, and Voyager will exist for several months.

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Visit by Prince Charles

Prince Charles of Wales visited the Jet Propulsion Laboratory on October 27, at his request. After viewing full-scale models of the Viking Mars Lander and the Voyager spacecraft, and visiting the Mission Control and Computing Center, the prince moved to the Voyager Mission Operations area, where he sent a command to Voyager 1, some 46 million kilometers (29 million miles) distant.

From the command console, the prince spoke by telephone with operators of the NASA/JPL Deep Space Station near Canberra, Australia, advising them that the command had been prepared and determining that the ground station transmitter modulation was on and "go for commanding."

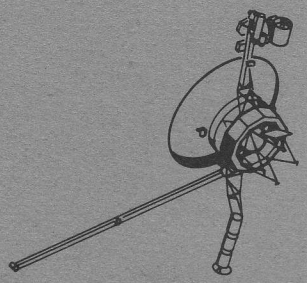
The prince pressed the command switch, sending DC-2A, Voyager's "ranging on" command, through the Australian station and up to the spacecraft.

At the speed of light, the signal reached Voyager 1 in 2½ minutes. In another 2½ minutes, acknowledgement that the spacecraft had received and acted upon the command was received on the ground and immediately printed out on a telemetry display at Prince Charles' console.

The DC-2A commands the spacecraft to allow the tracking stations of the Deep Space Network to determine precisely the distance, or range, to the Voyager by establishing a special closed-loop code between the ground and the spacecraft.

Prince Charles checks with tracking station operators in Australia prior to sending a command to the Jupiter-bound Voyager 1 spacecraft on October 27. With the prince in the Voyager Mission Control Center is JPL Director Dr. Bruce C. Murray.

Prince Charles reaches for button to send the command 29 million miles to Voyager 1. With him at the command console at JPL are Michael Devirian (back to camera) Voyager spaceflight operations director, and Evelyn Davis, command console operator. Partially hidden from view at left is John R. Casani, Voyager project manager. At far right, JPL Deputy Director C. H. Terhune, Jr.



MISSION STATUS BULLETIN

VOYAGER

November 29, 1977 **No. 12**

SUMMARY

Eighty-five days after launch, Voyager 1 is healthy and operating well. Cruising at 21 kilometers (13 miles) per second, the craft is over 92 million kilometers (57 million miles) from Earth. One-way communication time is about 5 minutes 6 seconds.

Voyager 2, 101 days after launch, continues to operate well, with no major problems. Its velocity is 19.7 kilometers (12 miles) per second. At nearly 95 million kilometers (59 million miles) from Earth, one-way communication time is about 5 minutes 12 seconds.

Voyager 1 is closing the gap between itself and its earlier-launched, but slower, companion, and will soon overtake it. Last week, the two craft crossed the orbit of Mars and flew by the Red Planet itself at a distance of 139 million kilometers (86 million miles) for Voyager 1 and 137 million kilometers (85 million miles) for Voyager 2.

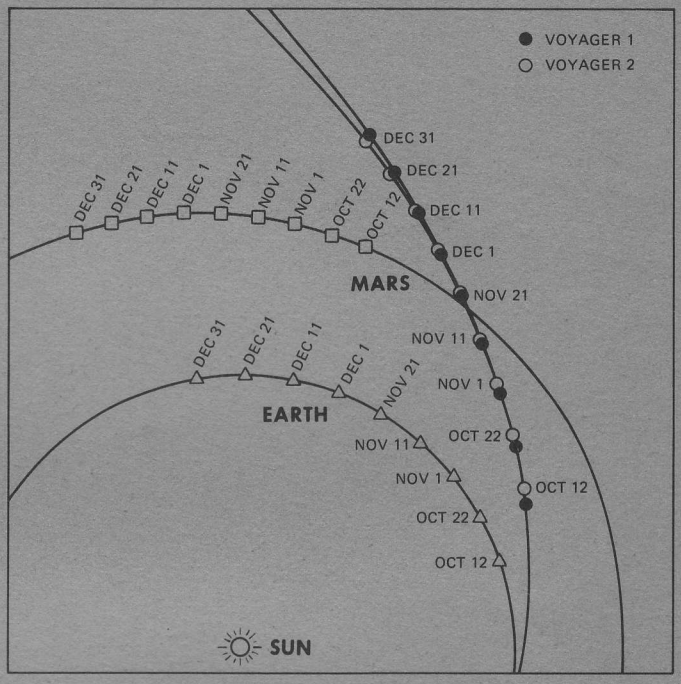
UPDATE

VOYAGER 1

Voyager 1 continues its cruise, returning data at 2560 bits per second (bps). Spacecraft activities include numerous instrument calibrations, including the sun sensors, magnetometers, photopolarimeter, plasma, and periodic engineering and science calibrations (PESCALs).

While Voyager 1 has a fuel margin of about 25 kilograms (55 pounds), fuel saving measures are being implemented on this craft as well as on Voyager 2. On Voyager 1, the sensitivity of the sun sensors has been altered slightly to reduce propellant consumption caused by thruster firings to maintain the Sun in the sensors' fields of view.

All science instruments aboard Voyager 1 are in good condition and operating properly when turned on. Periodic slews of the scan platform to various stars and planets continue for the photopolarimeter and ultraviolet spectrometer experiments.



"CATCH-UP". In this computer simulation, the positions of both spacecraft, Earth, and Mars are plotted at ten-day intervals. The spacecraft crossed the orbit of Mars about November 21, and Voyager 1 will overtake Voyager 2 in late December, almost 127 million kilometers (79 million miles) from Earth.

VOYAGER 2

Voyager 2 also continues in cruise mode, returning data at 2560 bps, with similar spacecraft activities occurring as on Voyager 1.

Satisfactory progress is being made in analyzing and solving for spacecraft problems.

The photopolarimeter (PPS) analyzer wheel remains stuck in position 2, but resolution of the problem is not urgent. The apparent cause is a failure in the multiplexer chip which selects the wheel position, and is under investigation.

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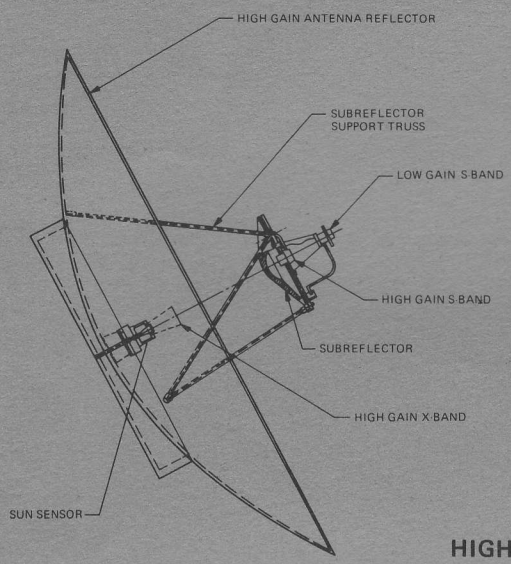
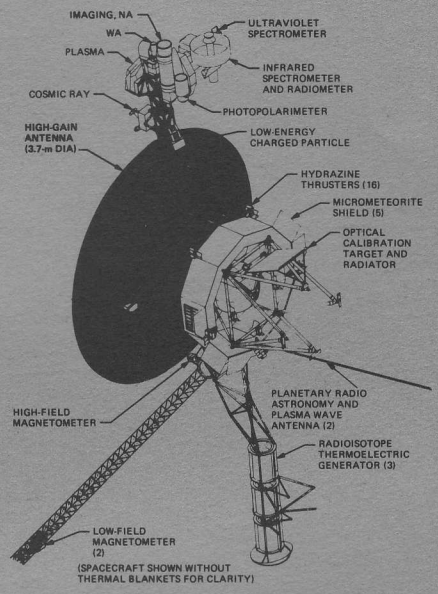
The low-energy charged particle (LECP) instrument is operating again after being turned off when a higher than acceptable temperature was noted on November 2. The overheating appears to correspond with turn-on of the X-band antenna, and is under study. A series resistor in the stepper motor may have been damaged by the high temperature, but the instrument is currently operating properly.

Several strategies have been devised and implemented to conserve fuel aboard Voyager 2, and studies indicate that there is an adequate supply – in fact a 9-kilogram (20-pound) margin – to support a Uranus encounter in January 1986. Although some attitude control functions and the trajectory correction maneuvers use hydrazine at rates greater than predicted, propellant savings resulted from (or will result from) the very stable propulsion module burn which boosted the spacecraft out of Earth orbit, the accurate Jupiter-bound trajectory, and the relocation of the post-Jupiter trajectory correction maneuver to 11 days after closest approach (including a small adjustment in the aiming point for the Ganymede flyby).

THE VOYAGER SPACECRAFT





HIGH GAIN ANTENNA ASSEMBLY

(This is the second in a planned series of brief explanatory notes on the spacecraft and its subsystems.)

Part 2 – High Gain Antenna

At first glance, Voyager's high-gain antenna dish is the most prominent feature of the spacecraft – in fact, a VW could park under its 3.66-meter (12-foot) diameter white umbrella.

Supported above the bus by a tubular trusswork, the dish is a reflector made of an aluminum honeycomb core surfaced on both sides with graphite epoxy-laminated skins – a lightweight yet durable combination to withstand the stresses of launch and the rigors of deep space.

The high-gain antenna assembly includes the sun sensors and the low-gain antenna as well. The sun sensors protrude through a cutout in the antenna dish.

The high-gain antenna is so-called because of its higher transmitting power, compared with the low-gain antenna. The high-gain antenna transmits and receives at two frequencies: the lower S-band and the higher X-band, while the low-gain antenna transmits and receives only at S-band.

The high-gain antenna, therefore, has two "feed horns", one for transmitting and receiving at S-band, and one for transmitting and receiving at X-band. The X-band feed horn is at the center of the dish. The S-band feed horns for the high-gain and low-gain antennas are mounted back-to-back on a three-legged truss work supported above the main dish. A smaller, secondary reflecting dish is mounted on the trusswork below the two S-band feed horns.

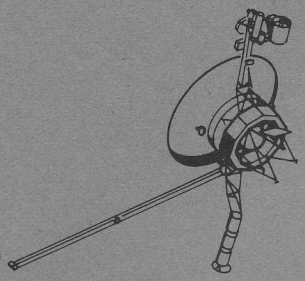
Communications during launch, near-Earth, and the early cruise phases of the mission were confined to the S-band and low-gain antenna. After the first 80 days of the mission, all communications – both S-band and X-band – are via the high-gain antenna, except for periodic science maneuvers and trajectory correction maneuvers when the low-gain antenna S-band will be used.

Why all the combinations of S- and X-band? There are several considerations. For example, different phases of the mission require different telemetry rates for the returning data; only the 64-meter antennas of the Deep Space Network can receive the X-band signals from the spacecraft.

Table 1 shows the relationships between the spacecraft and Earth-based antenna.

Table 1. Spacecraft-to-Earth Antenna Relationships

Antenna		Transmit	Receive
Spacecraft	Low Gain	S-band (2295 ±5 MHz)	S-band (2115 ±5 MHz)
	High Gain	S-band (2295 ±5 MHz) X-band (8422 ±20 MHz)	S-band (2115 ±5 MHz)
Earth (Deep Space Network)	26-meter (6)	S-band (2115 ±5 MHz)	S-band (2295 ±5 MHz)
	64-meter (3)	S-band (2115 ±5 MHz)	S-band (2295 ±5 MHz) X-band (8422 ±20 MHz)



MISSION STATUS BULLETIN

VOYAGER

January 5, 1978 **No. 13**

SUMMARY

Voyager 1 now rightfully owns its title, having taken over the lead from Voyager 2 about December 15. Voyager 1 is now farther from both Sun and Earth than Voyager 2, and will continue to increase its lead until it is four months ahead at Jupiter encounter in early 1979.

Both spacecraft are now more than 1 AU from Earth, and almost 2 AU from the Sun [an AU (astronomical unit) is the mean distance from the Earth to the Sun, about 150,000,000 kilometers (93,000,000 miles)].

Voyager 1 is about 177 million kilometers (110 million miles) from Earth, travelling with a velocity* of about 27 kilometers (16.7 miles) per second, relative to the Sun. One-way communications with the spacecraft now take 9 minutes 49 seconds.

Voyager 2 is about 174 million kilometers (108 million miles) from Earth, travelling with a velocity* of about 26 kilometers (16 miles) per second, relative to the Sun. One-way communications time is now 9 minutes 40 seconds.

*Beginning with this bulletin, the velocities given will be heliocentric, that is, with respect to the Sun. Previously-stated velocities have been geocentric, or, relative to the Earth. More meaningful comparisons can be made when using the relatively stationary Sun as a reference point rather than the ever-moving Earth.

The Night Sky —

Amateur astronomers may be interested in observing two of Voyager's goals — Jupiter and Saturn — now easily visible to the unaided eye in the night sky. Four more of Voyager's targets — the Jovian satellites Io, Europa, Ganymede, and Callisto — may be observed with the aid of a small telescope.

At the western edge of the constellation Gemini, Jupiter is presently the brightest object in the evening sky and is visible from sunset to sunrise as it moves across the sky from east to west. It is near Orion's Belt, an easily-identifiable row of three stars. On January 21, the giant planet will be visible about five degrees north of the full moon.

Saturn rises in the eastern sky in early evening and remains there until sunrise. Located in the constellation Leo, it is brighter than a nearby star, Regulus. On January 20, Saturn will be visible about one degree north of Regulus.

MISSION HIGHLIGHTS

Celestial Object Observed

An unusual object was detected during standard camera calibrations on December 24. The object appeared to be approximately 30 meters (98 feet) in length and was made up of nine distinct images in linear sequence trailed by a larger, rectangular unit. Spectral analysis of this object revealed traces of red velvet and mammalian cilia. Additionally, the object proved to be a strong radio source. Prompt evaluation of emitted frequencies revealed the following message: "Ho, Ho, Ho . . . and a Merry Christmas to ALL!"

And a Happy New Year, too!

Sequence Verification Tests

Cruise provides an opportunity for "getting acquainted" with the spacecraft, learning exactly how it will perform and react. As part of this "getting to know you" strategy, sequence verification tests were performed on both spacecraft during December.

The purpose of the tests is to serve as a proof of the computer programs now being written for the planetary encounter activities. They are a rehearsal for the busy times to come.

The sequences verify expected spacecraft performance in tests that cannot be performed on Earth prior to launch. Since the space environment cannot be totally duplicated in Earth laboratories, various assumptions were made during design and fabrication of the spacecraft, based on models of spacecraft performance. During cruise, these models will be verified and refined.

December's sequence verification tests concentrated primarily on three areas of interest: microphonics, boresighting, and imaging rates.

Microphonics. Several of the instruments aboard Voyager are especially sensitive to the motion and noise created by other activities aboard the spacecraft, such as scan platform slewing or the stepper motors on several instruments. The microphonics tests measure the sensitive instruments' reactions of these interferences so that the effects can be minimized or, in later data analysis, obvious reactions to spacecraft noise can be disregarded.

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The plasma instrument and infrared interferometer spectrometer are the most sensitive to motion and noise generated on the spacecraft by various actuations. The motion of the scan platform, as well as the motors which rotate wheels on the photopolarimeter, imaging, and low-energy charged particle instruments, create the most noise.

The effect of these combined motions and noises cannot be satisfactorily studied on Earth, as no vacuum chamber has yet totally simulated the vacuum environment of space. Even the low levels of noise in the test area affect the tests. In addition, the scan platform is difficult to maneuver on Earth due to the mass of the instruments, nearly 91 kilograms (200 pounds), perched on its tip.

Boresighting. All of the instruments aboard Voyager are interactive to some degree; that is, their data are supplementary and complementary. In particular, the ultraviolet spectrometer, photopolarimeter, and imaging cameras, all mounted on the scan platform, must be aligned to look at the same position at the same time. The boresight tests consist of slewing the scan platform across the sky to determine if the three instruments observe the same star at the same time and are therefore well-aligned. The tests verify that the alignment is the same as pre-launch.

Imaging Rate. Several instruments, including the imaging cameras, planetary radio astronomy subsystem, and plasma wave subsystem, must return data at the highest rate possible, 115 kilobits per second. Verification of proper performance at this rate is needed prior to encounter.

UPDATE

VOYAGER 1

During the sequence verification tests on December 14/15, the filter wheels of the imaging cameras aboard Voyager 1 were observed not to be stepping. The cameras were turned off and the heaters were turned on. Both the narrow- and wide-angle cameras were in the clear filter position when the cameras were turned off (both cameras also have seven other filters).

The source of the problem has not been isolated. A sequence of diagnostic tests has been developed and will be conducted in mid-January. It is expected that tests will prove that a redundant element can be implemented.

On December 13, Voyager 1 conducted a fairly extensive mapping of the Orion nebula. Both the ultraviolet spectrometer (UVS) and photopolarimeter (PPS) continue to observe a limited number of stellar targets. These observations are proving to be invaluable astronomical tools, providing precise pointing over an extended period of time, gathering original data on emissions in the ultraviolet and visible light ranges, and making fundamental science observations and calibrations.

VOYAGER 2

Voyager 2 completed the sequence verification tests December 5, 7, and 8 without incident.

On December 27/28, Voyager 2 performed a cruise science maneuver. The maneuver consists of rolling the spacecraft in one direction for about 5 hours and then rolling it about the roll axis for about 12 hours. The last roll turn was finished 20 seconds earlier than the computer expected, and a "safing" sequence was executed, one of the built-in safety features of the spacecraft. The turn tolerance will be adjusted to accommodate the spacecraft performance on future cruise science maneuvers.

The cruise science maneuver allows calibration of several instruments by turning the spacecraft to look at the entire sky. The scan platform instruments are able to map the sky as the spacecraft rolls, and the ultraviolet spectrometer and photopolarimeter make their observations against the total sky background. The magnetometers and plasma instrument also obtain calibration data.

A significant decrease in sensitivity has been noted on Voyager 2's infrared interferometer spectrometer (IRIS). The condition will be monitored over the next few months to detect stabilization or any further change. A deep space observation calibration is scheduled for February 8.

A degradation of the S-band radio solid-state amplifier in the high power mode has been noted. The amplifier has been switched to the low power mode and is being monitored. The radio system has built-in redundancy, using both the solid-state amplifier and a travelling wave tube amplifier.

THE VOYAGER SPACECRAFT

RADIOISOTOPE THERMOELECTRIC GENERATORS

(This is the third in a planned series of brief explanatory notes on the spacecraft and its subsystems).

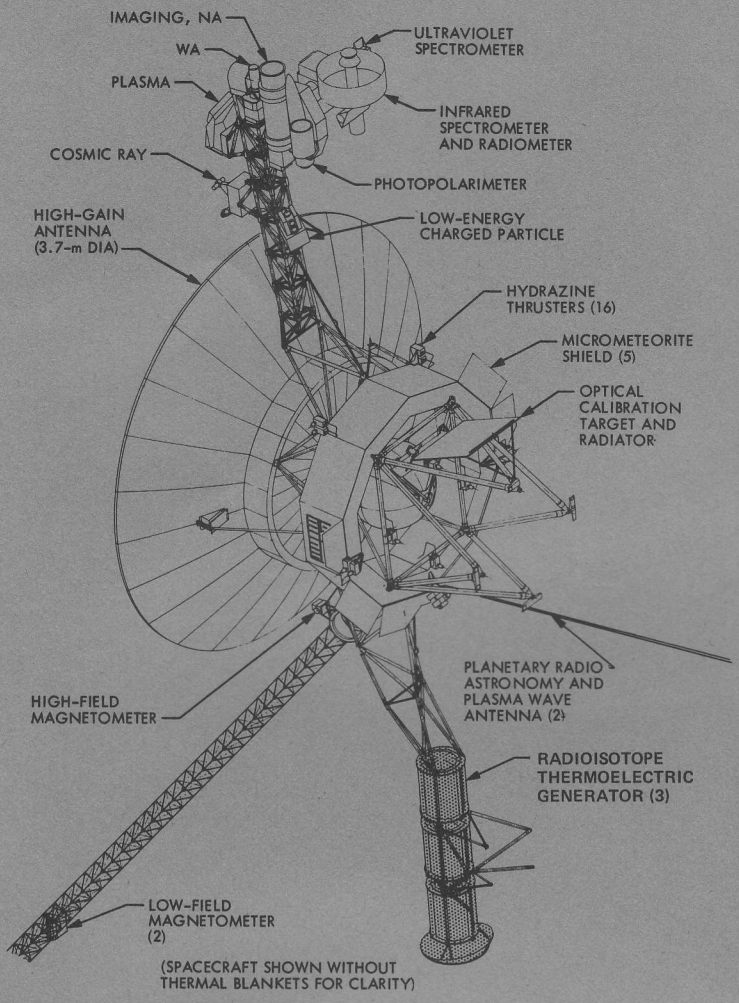
Far away from electrical outlets, and with no solar panels, Voyager needs power to operate its various motors, heaters, and other mechanical parts. Nuclear power provides the solution.

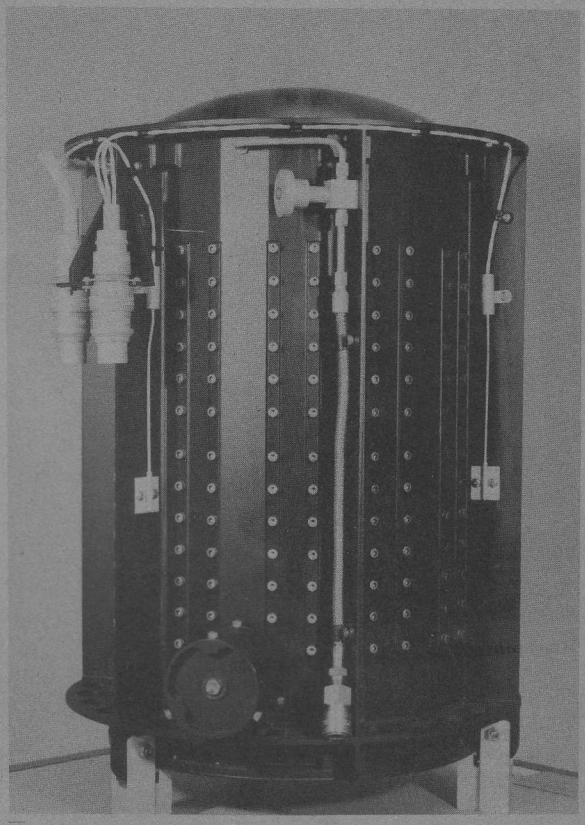
Each spacecraft carries three radioisotope thermoelectric generators (RTGs) mounted in tandem (end-to-end) on a boom which was deployed shortly after the spacecraft entered Earth orbit about one hour after launch. The generators are located on the boom 180° from the scan platform boom to minimize the effects the radiation they generate may have on the science instruments. The distance between the nearest RTG and the nearest science instrument on the scan platform boom is about 16 feet.

The RTG units convert to electricity the heat released by the decay of Plutonium-238, a radioactive isotope. The minimum total power available from the three RTGs ranges from about 423 watts within a few hours after launch to 384 watts after the spacecraft passes Saturn. The science instruments require about 105 watts of this total – slightly more than an ordinary household light bulb. The remaining power is used by other spacecraft subsystems.

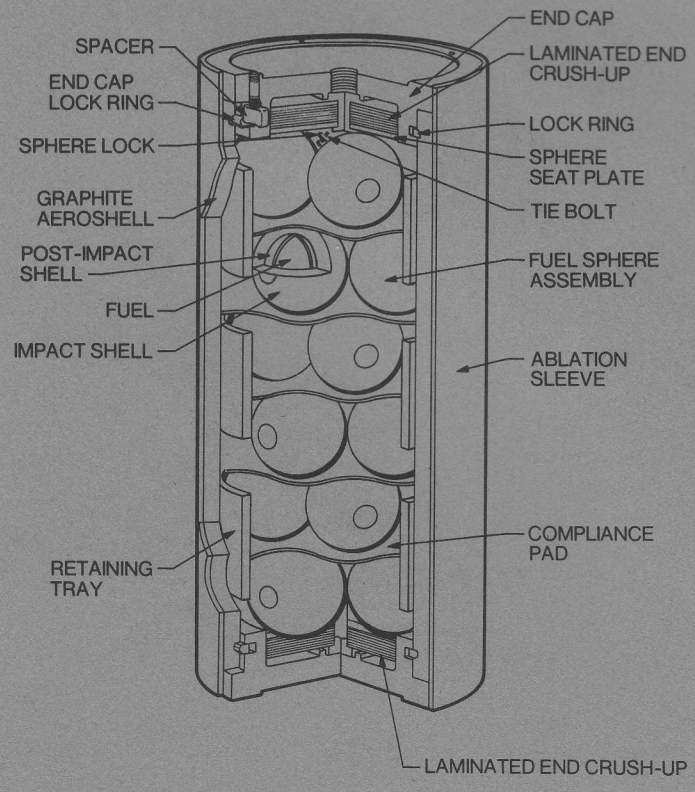
The RTGs are activated about 1 minute after liftoff when an inert gas in the generator interiors is expelled via a pressure relief device. The inert gas serves to prevent oxidation of the hot components of the units. After activation, the RTGs do not reach full power until about six to eight hours after launch, when the spacecraft is well beyond Earth.

Power from the RTGs is held at a constant 30 volts direct current (Vdc) by a shunt regulator. The 30 volts is supplied directly to some spacecraft users and is switched to others in the power distribution assembly. The main power inverter converts the 30 volts direct current to 2.4 kiloHertz square wave (ac) for use by most spacecraft subsystems.

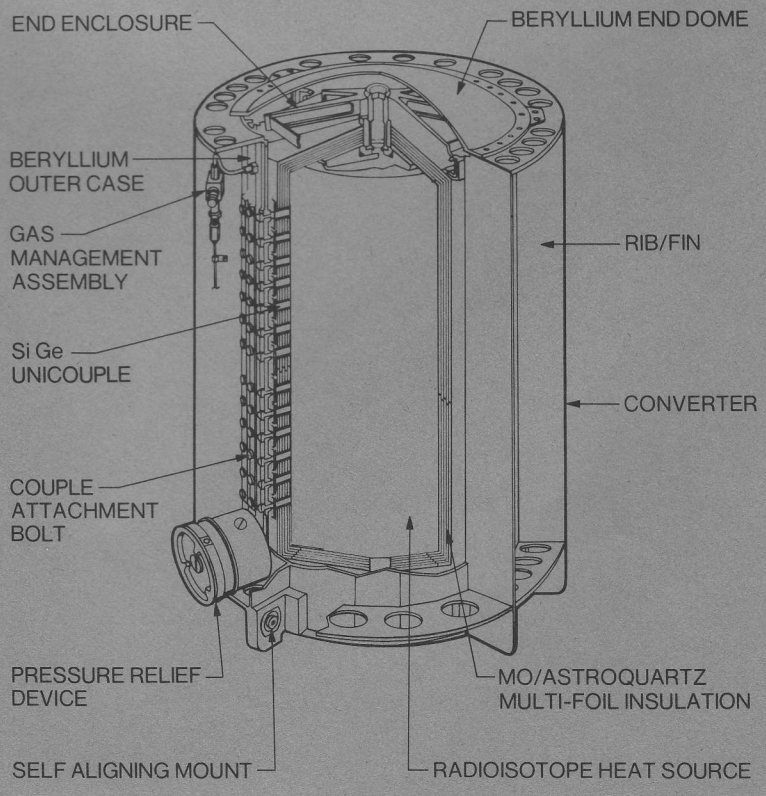




Model of Radioisotope Thermoelectric Generator Unit

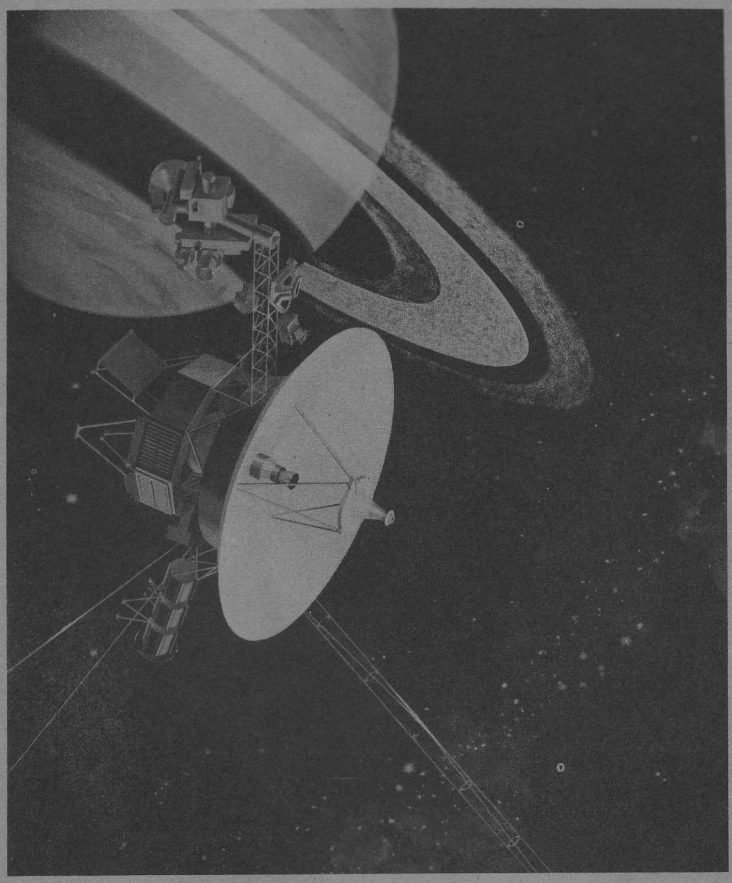


Heat Source for Radioisotope Thermoelectric Generator

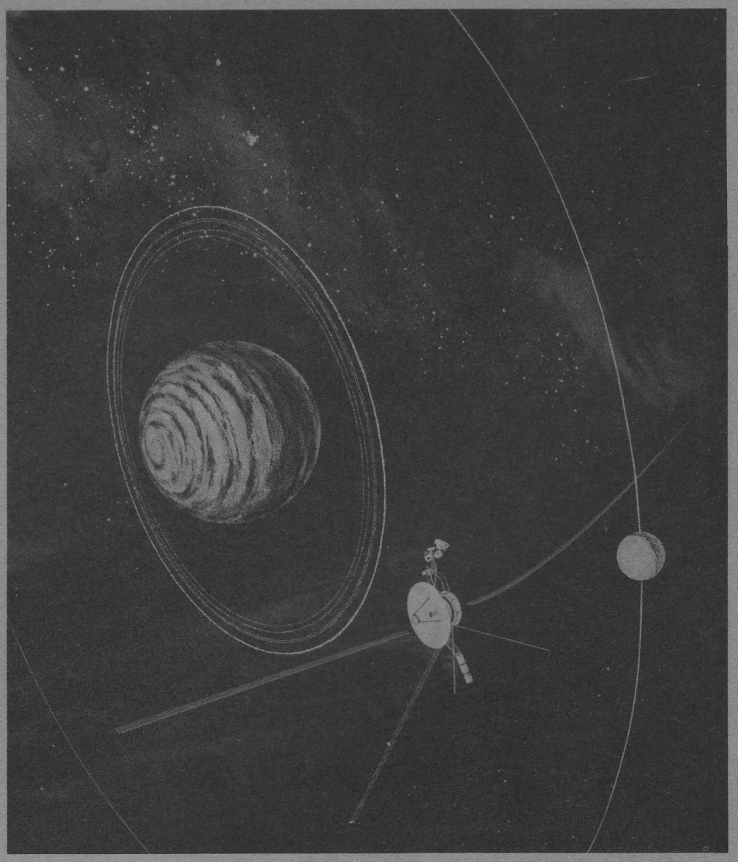


Radioisotope Thermoelectric Generator

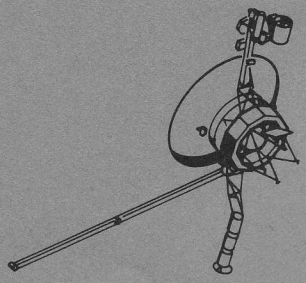
A CLOSE LOOK AT JUPITER – Voyager spacecraft aims its instrument scan platform at the planet Jupiter in this painting depicting a major step in the mission. Voyager 1 will fly past Jupiter March 5, 1979, and then will continue on to ringed Saturn. Voyager 2 will arrive at Jupiter July 9, 1979, and will follow its predecessor to Saturn.



PASSING SATURN – The Voyagers will arrive at Jupiter in March and July 1979, and at Saturn in November 1980 and August in 1981. Each craft carries ten scientific instruments to measure interplanetary space, the planets, and their satellites (including photography). An eleventh experiment uses Earth and spacecraft radios to measure planet and satellite atmospheres.



ON TO URANUS – This painting depicts Voyager 2 observing Uranus in January 1986. The option to target for Uranus exists only for Voyager 2. Uranus is tilted on its axis so its poles point towards the Sun. Its rings were discovered in 1977.



MISSION STATUS BULLETIN

VOYAGER

January 16, 1978 **No.14**

EARTH AND MOON — This picture of a crescent-shaped Earth and Moon — the first of its kind ever taken by a spacecraft — was recorded September 18, 1977, by Voyager 1 when it was 11.66 million kilometers (7.25 million miles) from Earth. The Moon is at the top of the picture and beyond the Earth, as viewed by Voyager. In the picture are eastern Asia, the western Pacific Ocean and part of the Arctic. Voyager 1 was directly above Mt. Everest (on the night side of the planet at 25 degrees north latitude. The photo was made from three images taken through color filters, then processed by the Image Processing Lab at the Jet Propulsion Laboratory. Because the Earth is many times brighter than the Moon, the Moon was artificially brightened by a factor of three relative to the Earth by computer enhancement so that both bodies would show clearly in the prints.

"We have put our ships into the cosmic ocean. The waters are benign and we have learned to sail. No longer are we bound to our solitary island . . . Earth!"
— Carl Sagan

"So far we have satisfied all of our objectives . . . thanks to all of you. I look forward with excitement to the discoveries that Voyager holds in store for us."

— John Casani
Outer Planets Project Manager
Jet Propulsion Laboratory

"The development of a spacecraft with the engineering and scientific sophistication and capability of Voyager extends engineers, scientists, and managers to the frontiers of creativity and technology . . . Congratulations to the Voyager Team. . ."

— A. Thomas Young
Director, Lunar and Planetary Programs, NASA Office of Space Sciences

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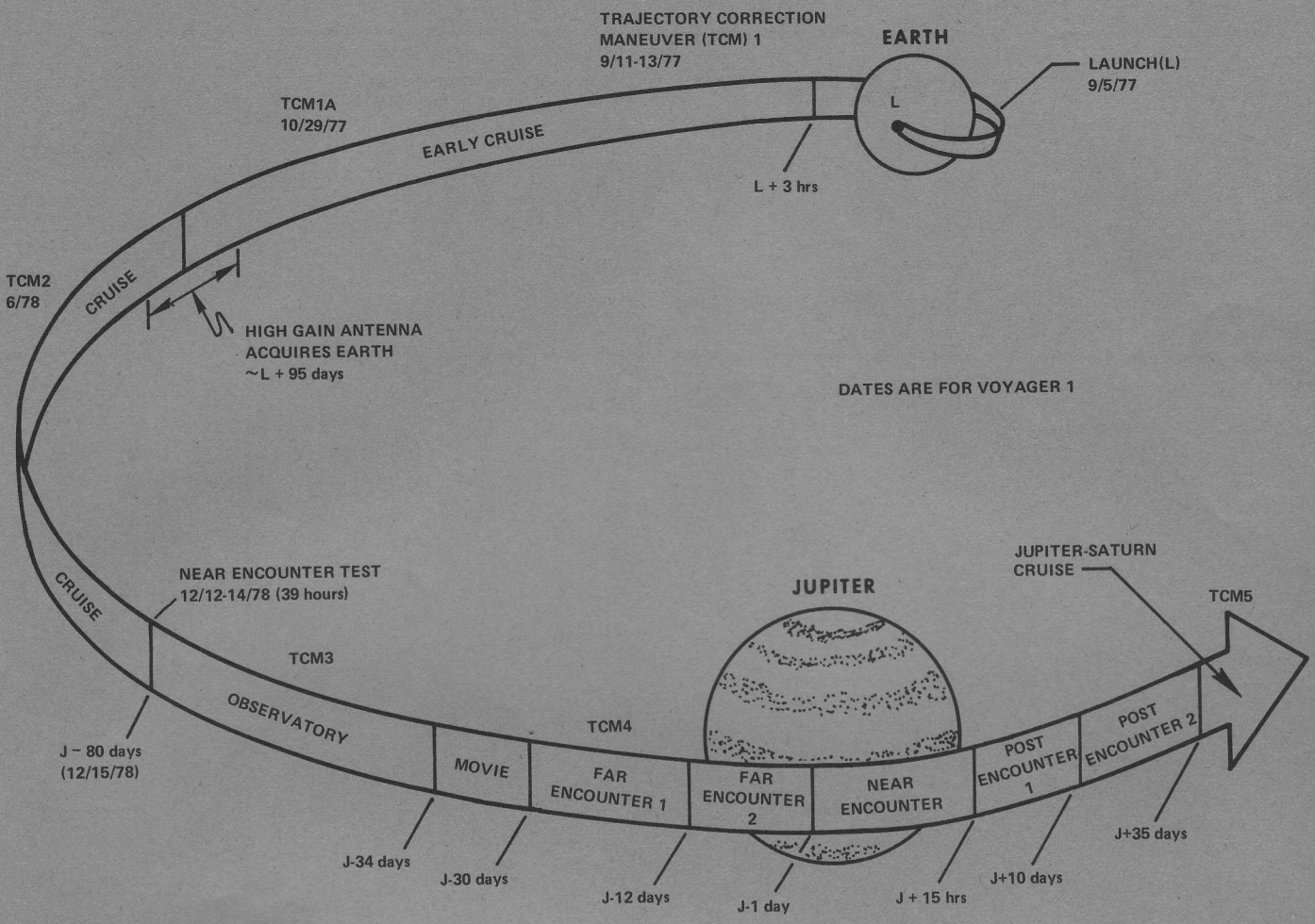


EARTH–TO–JUPITER MISSION PHASES. While Voyager flies on toward Jupiter, work continues on Earth for the planetary and satellite encounters to come. This sketch of the mission shows the planned Earth-to-Jupiter phases for both missions; dates and times given are for Voyager 1, launched September 5, 1977.

The early cruise phase lasted from post-launch to about 95 days into the flight. One trajectory correction maneuver (TCM) and a "clean-up" TCM were executed during the early cruise phase.

The cruise phase officially began when the high-gain antenna was turned toward Earth to remain in that position for most of the mission. The antenna must point toward Earth for communications. During the long cruise phase, nearly a year, one TCM is planned.

In December 1978, during the last three days of the cruise phase, the near encounter test (NET) will be performed. The NET will be an actual performance of the activities scheduled for the period of closest approach to Jupiter.

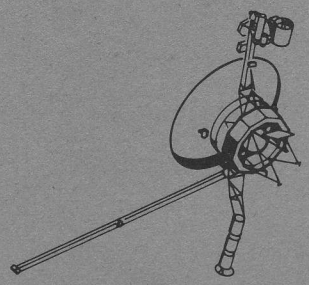
Eighty days and approximately 80 million kilometers (50 million miles) from the Giant Planet, the Jupiter observatory phase will begin, about December 15, 1978. Following a quiet period over the holidays, periodic imaging with the narrow-angle camera will begin on January 4, 1979. A third TCM is planned during this period.

In early February 1979, a four-day movie sequence will record 10 revolutions of the planet, photographing the entire disk.

Following the movie phase will be the far encounter phases, as the spacecraft zeroes in on the planet, closing to 30 million kilometers (18.6 million miles) at 30 days out. The far encounter phases, from early February to early March 1979, will provide unique observation opportunities for the four largest satellites – Io, Europa, Ganymede and Callisto – and a crossing of the bow shock of the Jovian magnetosphere, of great interest to all of the fields and particles instruments. One TCM is planned during the far encounter phase.

For Voyager 1, near encounter will be a 39-hour period packed with close-range measurements by the spacecraft's 11 science experiments. On the outbound leg, five Jovian satellites – Amalthea, Io, Europa, Ganymede, and Callisto will also receive close-range scrutiny by the various science instruments. Passing 280,000 kilometers (174,000 miles) from the visible surface of Jupiter, Voyager 1 will then whip around the backside of the planet, passing out of view of the Earth for a brief two hours.

The post encounter phases, from the end of near encounter to about 35 days later, will continue observations as the planet is left behind. Using the gravity of Jupiter to slingshot it on its way, Voyager 1 will flash onward toward the ringed planet Saturn, about 800 million kilometers (500 million miles) and 19 months distant. Voyager 1 will study Saturn from August through December 1980.



MISSION STATUS BULLETIN

VOYAGER

February 21, 1978 **No. 15**

SUMMARY

Now over 322 million kilometers (200 million miles) from Earth, Voyager 1 is operating normally, with a velocity of about 23 kilometers (14 miles) per second relative to the Sun. At the speed of light (and radio waves), one-way communication time is 17 minutes 48 seconds.

Voyager 2 is nearly 313 million kilometers (195 million miles) from Earth, travelling at a velocity of about 22 kilometers (13.7 miles) per second relative to the Sun. One-way communication time is 17 minutes 18 seconds, half a minute less than Voyager 1. Voyager 2 is operating normally.

UPDATE

VOYAGER 1

In early January, Voyager 1 completed its first test and calibration of the magnetometers' mechanical flippers. The magnetometer sensors, located on a 13-meter (43-foot) boom to minimize the effects of the spacecraft's own magnetic field, are flipped end-to-end and calibration measurements are taken. The commands for this sequence are sent during real time rather than incorporated into an automatic computer sequence, so that the event may be monitored as it happens.

The filter wheels on the cameras are stepping normally again after being turned off during the December sequence verification tests. Diagnostic tests have identified a bad memory location in the flight data subsystem computer, and a spare memory location is now being used and will be used in future programs.

Two changes have been made in Voyager 1's Earth-to-Jupiter mission phase schedule. The second trajectory correction maneuver, previously scheduled for June 1978, will now be executed in September 1978. In addition, the start of the Jupiter Observatory data acquisition has been moved to January 4, 1979 to allow personnel a quiet period over the winter holidays before the start of intensive activities which will span eight months as first one, then the other, spacecraft observes Jupiter.

On February 17, Voyager 1 entered a safing routine before completing a cruise science maneuver. A complete cruise maneuver involves 10 360° yaw turns and 24 roll turns, taking 18 hours to complete, and allows routine calibration of several instruments by looking at the entire sky.

VOYAGER 2

A test of the magnetometers' mechanical flippers was successfully completed on January 24.

A target maneuver is scheduled for March 7. The purpose of the maneuver is to calibrate the imaging cameras, photopolarimeter, and infrared interferometer spectrometer, all mounted on the scan platform at the tip of the science boom. A series of spacecraft turns positions the target plate, mounted below the bus at an angle to the scan platform, in the sunlight, so that each instrument can "look" at the reflective plate as the scan platform is maneuvered. The sequence requires about 5 hours to complete. Target maneuvers will be performed regularly on both spacecraft throughout cruise.

THE VOYAGER SPACECRAFT

(This is the fourth in a planned series of brief explanatory notes on the spacecraft and its subsystems.)

Part 4 — Cosmic Ray Investigation

When cosmic rays, high-energy radiation from outer space, were discovered less than 70 years ago, they caught the attention of the public and fired the imaginations of science fiction writers, who quickly invented cosmic ray guns, those deadly weapons of invading aliens. Although much has been learned about these phenomena in the intervening years, and cosmic ray guns have given way to lasers, phasers, and light sabers, many questions remain unanswered, or, as is often the case in scientific inquiry, some answers have only raised more questions.

Cosmic rays are the most energetic particles found in nature and are atomic nuclei, primarily protons, and electrons. They are comprised of all elements known to man. Over certain energy ranges and at certain periods of time, the elemental content of cosmic rays is similar in proportion to that of the matter of the solar system. Generally, however, their composition varies significantly with energy, indicating that a variety of astrophysical sources and processes contribute to their numbers.

Cosmic rays could pose a hazard to future space travellers. They can also cause mutation by altering or destroying genes. Although it is unlikely that life on Earth could be

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affected much (our atmosphere shields us), cosmic rays may play a role in organic evolution in space. Cosmic rays may, as we search for their origins, tell us much about our solar system and its origins and processes. Cosmic rays, which are material samples from the galaxy, can tell us much about how stars synthesize (cook) the elements. In addition, cosmic ray studies have contributed greatly to the field of subnuclear physics, giving us mesons, hyperon, muons, positrons, and neutrinos, long before they were artificially created in atomic accelerators in Earth's laboratories.

Early cosmic ray studies sought to identify the origin of cosmic rays in specific atomic reactions, but today the emphasis has shifted to study of the acceleration (pull) of ions by electromagnetic fields which are thought to exist in the interstellar spaces or in the neighborhood of certain celestial bodies.

Experiment Objectives

The Voyagers carry identical cosmic ray experiments, one of several fields and particles studies on the mission. The investigations will provide data on the energy content, origin and acceleration process, life history, and dynamics of cosmic rays in the solar system and nearby interstellar space.

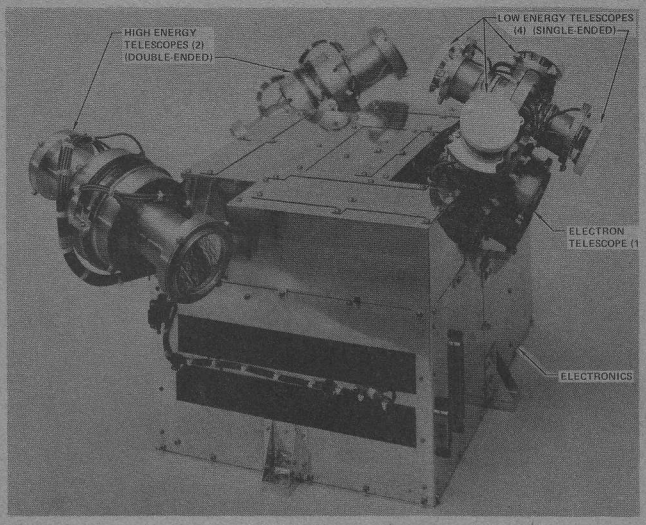
The investigations will analyze, at increasing distances from the Sun, the energy spectra and elemental composition of all cosmic-ray nuclei from hydrogen through iron, over an energy range from about 1 million to 500 million electron volts. (In comparison, medical x-rays pack about 10,000 electron volts of energy, while an atom in an exploding atomic bomb carries about 10 million electron volts.)

At ever increasing distances from the Sun, the experiments will gather data over a wide range of mass, charge, and energy, with high resulotion and at high data rates. Close in, the Sun's magnetic field and plasma tends to prevent entry of lower-energy cosmic rays from the galaxy. Farther from the Sun, presumably at distances of 20 to 30 AU (the Earth's distance from the Sun is 1 AU), one hopes to discover, for the first time, low-energy galactic particles and to learn about their sources and how these particles are accelerated to their immense energies. The energies and streaming patterns of particles can reveal much about their origin and where they have been since.

Instrument Package

There are two basic types of instruments used in cosmic ray studies. One type uses track visualization, in which the paths of cosmic ray particles are made visible and photographed. The second, electron counting, converts all or part of a particle's kinetic energy to electrical impulses which are recorded. The Voyager instruments are of the second type.

Each Voyager cosmic-ray experiment, mounted about half-way out on the science boom, consists of seven fixed-mounted telescopes: four single-ended low-energy telescopes, two double-ended high-energy telescopes, and one electron telescope. All use arrays of solid-state detectors, silicon wafers of varying thicknesses (35 microns to 6 millimeters) and area (2.8 to 9.6 square centimeters), each cut from carefully-grown pure crystals. Various electrically-conducting metals (aluminum, gold, or lithium) are laid on the semi-conductor wafer surfaces to give them their sensor properties. The energy,

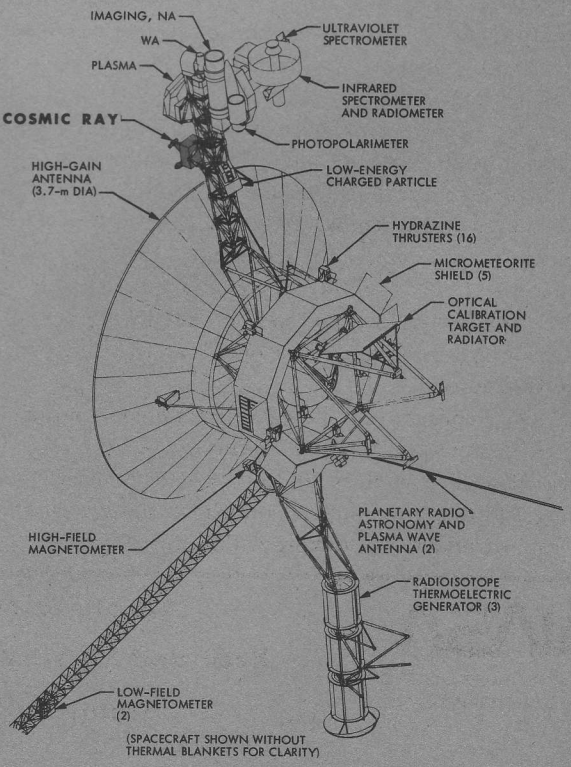


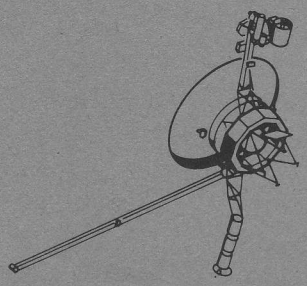
mass, and direction of each entering particle is measured by the number of detectors it penetrates, the electrical charge it deposits, and which telescope it enters. The telescopes are positioned at various angles to that the experiment does not need spacecraft maneuvers to gather samples from all directions.

The instrument package weighs 7.25 kilograms (16 pounds), measures about 20 x 30.5 x 25 centimeters (8 x 12 x 10 inches) and draws 5.2 watts of power.

Principal investigator for the experiment is Dr. R. E. Vogt of the California Institute of Technology and Chief Scientist at the Institute's Jet Propulsion Laboratory. Co-investigators are Dr. J. R. Jokipii (University of Arizona), Dr. F. B. McDonald (Goddard Space Flight Center and the University of Maryland), Voyager Project Scientist Dr. E. C. Stone (Caltech), Dr. B. J. Teegarden (Goddard), Dr. J. H. Trainor (Goddard), and Dr. W. R. Webber (University of New Hampshire).

Goddard Space Flight Center, Greenbelt, Maryland, built the high-energy telescopes, while Caltech built the low-energy and electron telescopes, as well as the bench checkout equipment for pre-flight testing.





MISSION STATUS BULLETIN

VOYAGER

March 1, 1978 **No. 16**

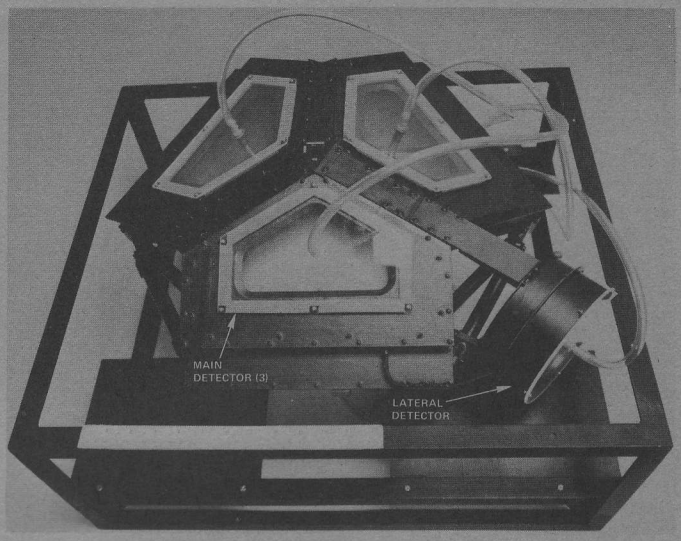
SUMMARY

A temporary suspension of all but essential spacecraft activity has been directed so that full attention can be concentrated on understanding several new spacecraft problems and on maintaining schedules in preparation for Jupiter encounter.

Several problems aboard Voyager 1 are under investigation, including the cruise science maneuver abort on February 17, a degradation in sensitivity of the plasma instrument, and a problem in maneuvering the scan platform. Tiger teams are currently analyzing the problems to understand them and their effects.

Voyager 1 is about 349 million kilometers (217 million miles) from Earth, nearly six months into its journey with almost 10 months to go before the start of Jupiter observations. One-way communication time is 19 minutes 18 seconds.

One-way communication time with Voyager 2 is 18 minutes 42 seconds, at a distance of nearly 339 million kilometers (210 million miles) from Earth. Voyager 2's observations of Jupiter will begin in about 13 months.



PLASMA INSTRUMENT. The protective covers on the three apertures of the ailing main detector were removed before launch, along with the piping which filtered clean cool air into the instrument before launch. The unaffected side-mounted detector is in the foreground in this photograph.

UPDATE

VOYAGER 1

Cruise Science Maneuver

A routine cruise maneuver to calibrate several science instruments by turning the spacecraft to scan the entire sky was automatically terminated before completion on February 17 when the command control subsystem (CCS) computer entered a failure protection mode.

The cruise maneuver consists of ten complete 360° yaw turns, followed by sun acquisition, and then 24 complete 360° roll turns. Apparently, the sun sensors did not find the sun as planned after the ten yaw turns, and a pitch and yaw maneuver, as part of the sun loss routine, was required to regain solar reference.

The spacecraft normally uses the sun and the star Canopus as references to maintain a steady position rather than tumble about in space, except when on-board gyros are commanded to be used as the reference. During the yaw turns, gyro references were in use, and some form of gyro-induced error is suspected as the cause of the problem, since sun sensor data indicates a difference between expected and actual sun position after each complete yaw turn.

The data from the maneuver is being analyzed in detail to fully understand the problem and to determine its affect on future operations.

Plasma Instrument

Although apparently unrelated to the events causing the cruise maneuver abort, a problem in Voyager 1's plasma instrument was also detected February 17. The sensitivity of the main cluster of three detectors appears to have dropped significantly. Initial indications are that the science objectives can still be met at Jupiter; however, during cruise, measurements of positive ions at the lower energy levels in interplanetary space will be significantly affected. The instrument is designed to measure ions in the energy range from 10 to 5950 electron volts. The side-mounted detector, positioned at right angles to the ailing main cluster (which points toward Earth), is unaffected and working as planned.

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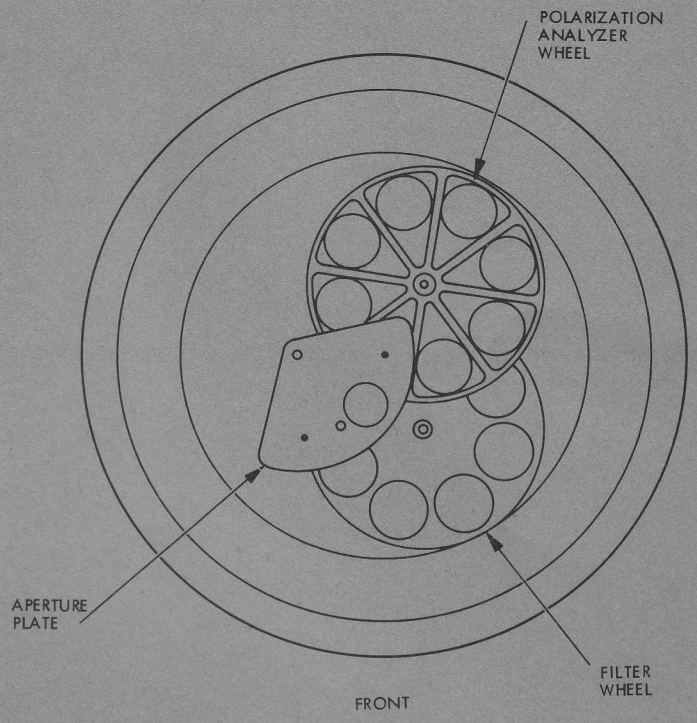
Scan Platform

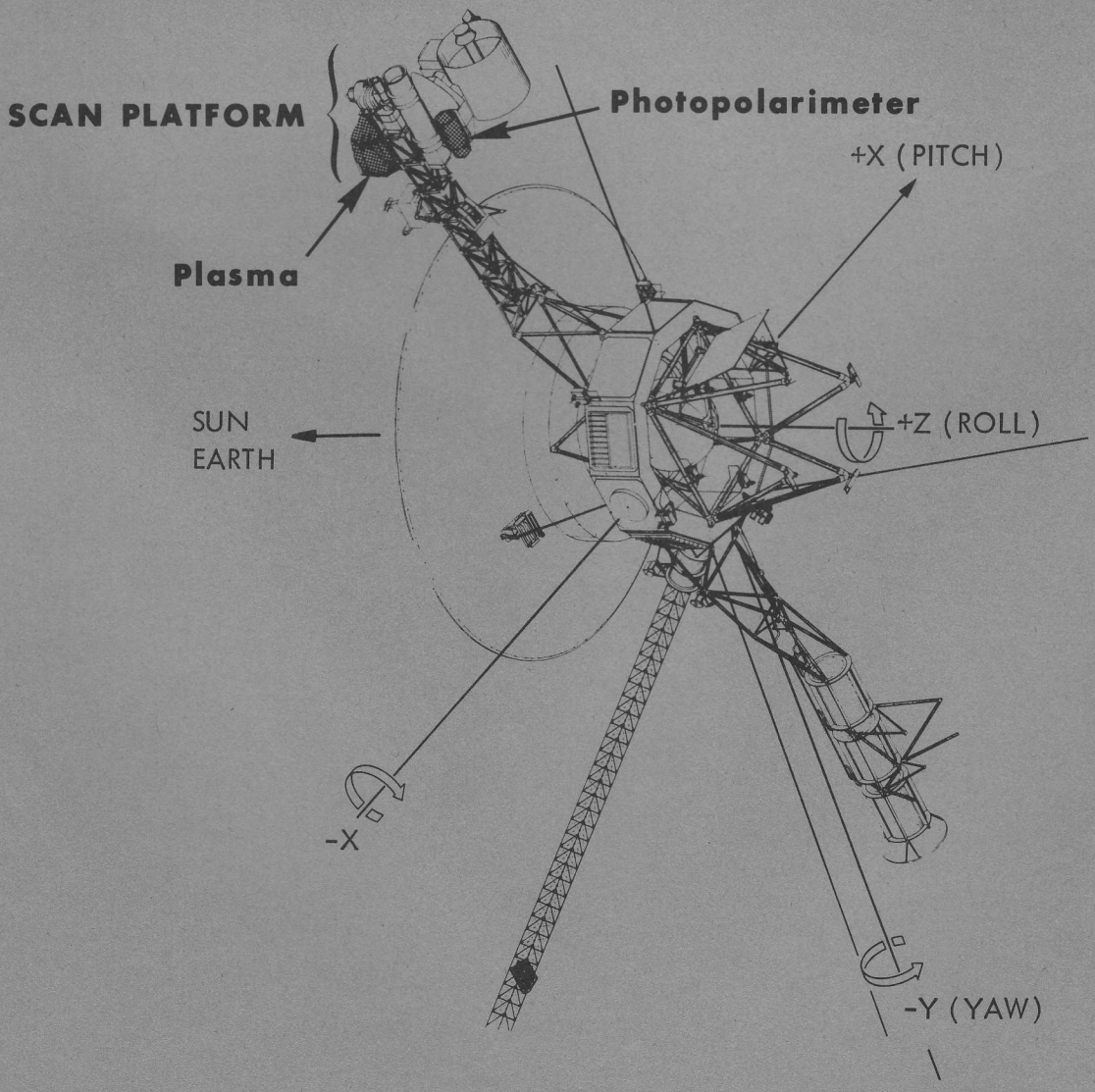
During a calibration of the scan platform on February 23, the platform's azimuth movement appears to have gradually slowed and did not reach the desired position in the hour allowed. When the hour was clocked by the attitude and articulation control subsystem (AACS) computer, the calibration was terminated. Analysis is underway to determine the cause and what remedies can be taken.

VOYAGER 2

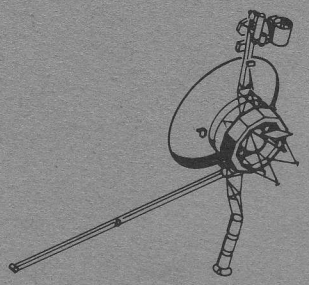
Voyager 2 presented a not altogether unpleasant surprize when it was detected that the stuck analyzer wheel of the photopolarimeter instrument appears to have become unstuck and operable. The wheel, stuck since shortly after launch, appears to be stepping properly, but further study is needed before concluding that the instrument is operating normally again. At nearly the same time, the filter wheel began to display erratic behavior, and the instrument has now been turned off until these latest developments can be understood. The normal operating mode of the instrument is to step through 40 filter/analyzer wheel combinations once every 24 seconds to provide intensity and polarization measurements of scattered sunlight at selected wavelengths.



PHOTOPOLARIMETER (PPS). In the normal operating mode, the instrument steps through 40 filter/analyzer wheel combinations every 24 seconds.



SPACECRAFT AXES



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VOYAGER

March 24, 1978 **No. 17**

IT'S MOVING!

VOYAGER 1

Scan Platform

Operating in low gear to obtain the most torque, Voyager 1's science scan platform has been successfully maneuvered in two separate tests. The platform, which slowed to a standstill during an azimuth slew on February 23, was successfully moved on March 17 and again on March 23. Project officials are expressing cautious optimism that planned platform operation at Jupiter encounter will be achievable.

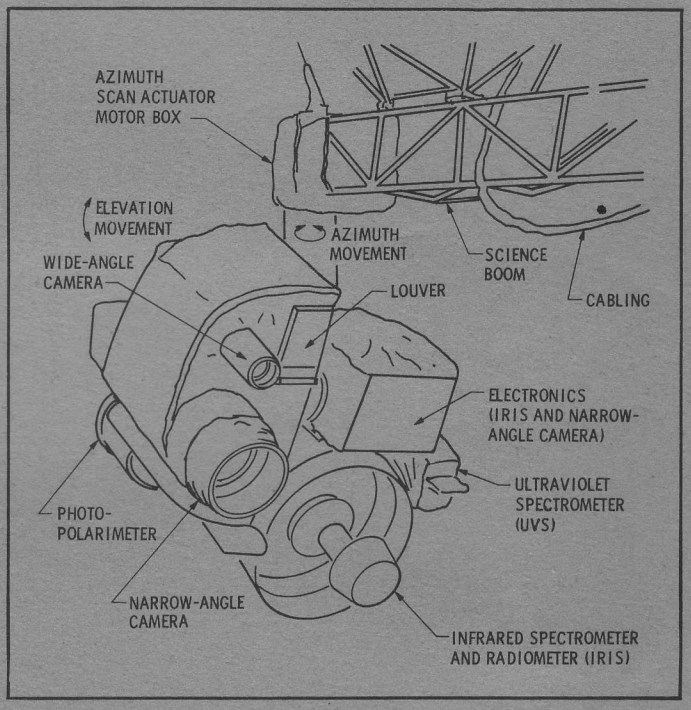
Moving at a slow speed of 0.0052 degrees per second, the platform was commanded on March 17 to back off a mere −1.5 degrees in azimuth from its stuck position, but data indicate this slew stopped short of its target and showed some unexplained characteristics. In the same test, two later slews at +9.0 degrees azimuth and +3.0 degrees elevation were also commanded and successfully completed.

On March 23, a five-hour sequence of four slews moved the platform through several positions away from the area where it had stalled, ending at the position most favorable to remain in should the platform fail to respond at a later date.

The platform can be moved (slewed) in one direction at a time, either azimuth or elevation, at one of four pre-selected rates: 0.0052, 0.0833, 0.333, or 1.000 degree per second. The lowest speed is required by the ultraviolet spectrometer experiment and also provides the most torque.

At the rate of 0.0052 degrees per second, a full 360-degree turn about an axis would take 20 hours to complete. At the fastest rate, 1 degree per second, a full turn would take 6 minutes. The platform cannot turn a continuous full circle about either of its two axes, however, because of mechanical limitations (for example, twisting of the cables). The azimuth range is 360 degrees and the elevation range is 210 degrees (including overtravel).

(contd)



SCAN PLATFORM. The science scan platform can be rotated about two axes to provide precision pointing for its four optical instruments.

SUMMARY

Both spacecraft are now closer to Jupiter than to Earth, in straight line distances. Six months after launch, Voyager 1 is about 426 million kilometers (265 million miles) from Earth and 366 million kilometers (227 million miles) from Jupiter. Due to the arc of the flight path, however, the craft will continue to chase the giant planet through space before closing in to begin Jupiter observations at a distance of about 80 million kilometers in January 1979, less than 10 months from now.

Voyager 2 is about 412 million kilometers (256 million miles) from Earth and 380 million kilometers (236 million miles) from Jupiter. Its journey will continue more than a year before Jupiter observations begin in April 1979.

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The 103-kilogram (226-pound) platform, located at the end of the 2.3-meter (7.5-foot) boom, provides precision pointing about two axes for four instruments: the ultraviolet spectrometer (UVS), infrared spectrometer and radiometer (IRIS), photopolarimeter (PPS), and a two-camera imaging system (ISS).

Photopolarimeter

Voyager 1's photopolarimeter instrument was turned on again on March 15 and is operating normally.

Plasma Instrument

The plasma instrument performance continues to degrade, and is being closely monitored. The sensitivity of the instrument's main detector dropped significantly on February 17. In early March, further change was observed, and it now appears that the Jupiter encounter objectives will be affected, as well as the cruise measurements. The instrument's side-detector continues to operate well.

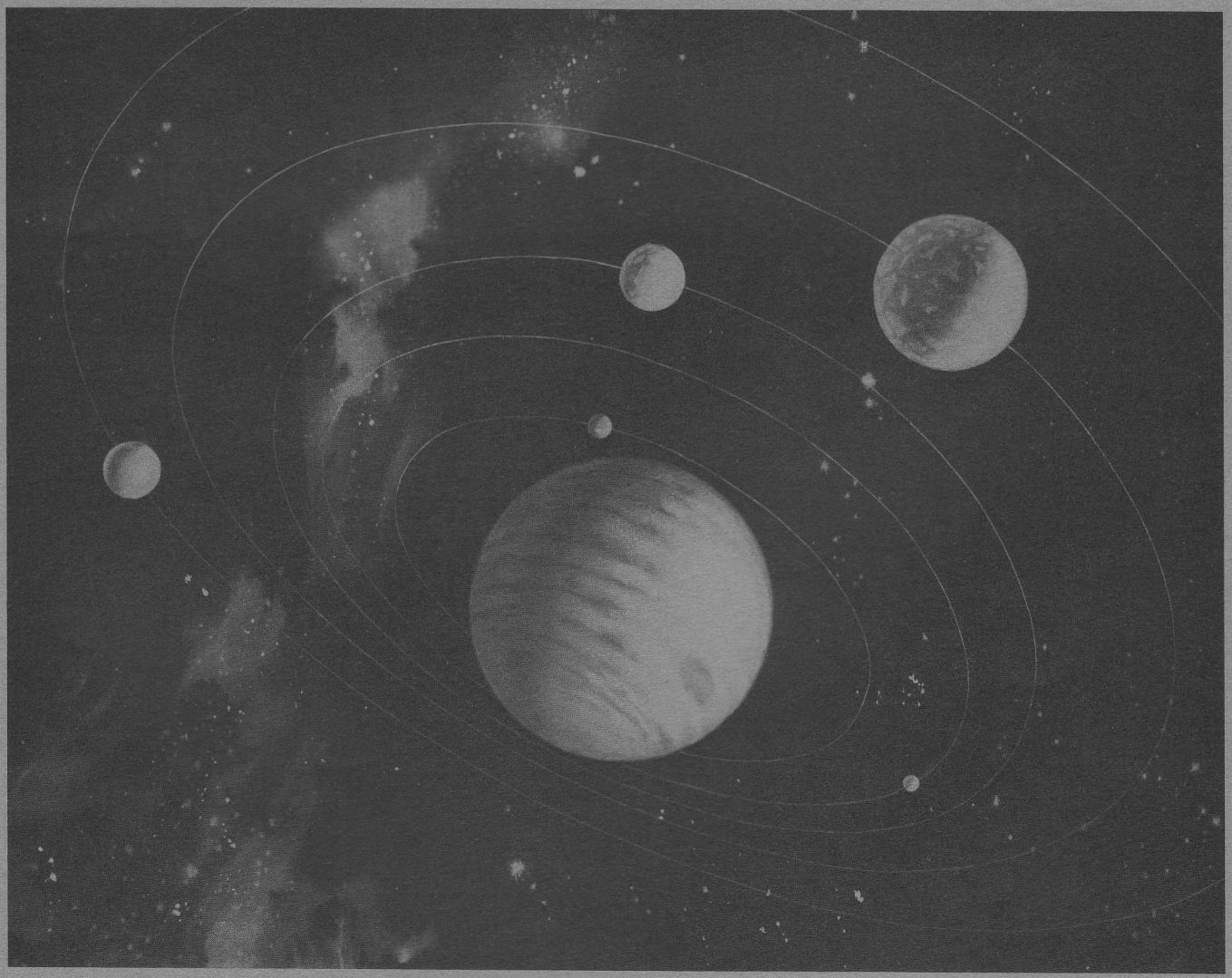
High Gain Antenna Solid State Amplifier

Some possible degradation in the high gain antenna's solid state amplifier has been detected. Because of a similar problem on Voyager 2 which resulted in switching to the backup travelling wave tube amplifier, the situation on Voyager 1 will be monitored closely.

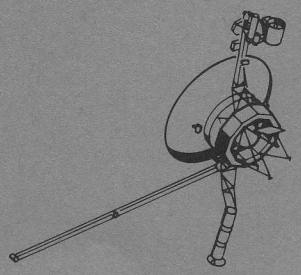
VOYAGER 2

Voyager 2 is cruising quietly, performing routine instrument calibrations. A target maneuver was successfully completed on March 7 to calibrate the scan platform instruments.

The photopolarimeter was turned on again on March 14 and is operating normally. Although the troublesome analyzer wheel is apparently unstuck and operable, it is not being stepped currently.



Jupiter and five of its moons: (ranging outward from the planet) Amalthea, Io, Europa, Ganymede, and Callisto.



MISSION STATUS BULLETIN

VOYAGER

April 7, 1978 **No. 18**

SUMMARY

Voyager 1's scan platform has been moved in several directions at several speeds during the past week. The craft is now over 472 million kilometers (293 million miles) from Earth, travelling at a velocity of about 21 kilometers (13 miles) per second relative to the Sun. One-way communication time is now slightly more than 26 minutes.

First indications are that Voyager 2's main radio receiver fuses have blown and that a tracking loop capacitor in the backup unit may be faulty. At a velocity of 19.9 kilometers (12.4 miles) per second relative to the Sun, Voyager 2 is about 456 million kilometers (283 million miles) from Earth. One-way light time is 25 minutes 11 seconds.

UPDATE

VOYAGER 1

Scan Platform

Voyager 1's scan platform has been roving the area of the "science-preferred position", executing ground-commanded slew sequences which exercised various directions, magnitudes, and rates of motion. The science-preferred position, at 235 degrees azimuth and 115 degrees elevation, is the most favorable position for the platform at Jupiter encounter should it fail at a later date to respond to commands, as it did on February 23.

The area in which the initial stall occurred has been avoided in the recent tests, and there is some concern that a problem may still exist in that area (45 degrees azimuth and 193 degrees elevation). Several of the spacecraft sequences already completed for Jupiter encounter require passing through the questionable area.

In an effort to pinpoint the cause of the February 23 stall, tests on April 4 provided data on platform performance during a cooling trend by turning off the scan coil heater for 24 hours. A test is being planned to exercise the platform as the scan coil heater warms the actuator.

VOYAGER 2

Communications

Voyager 2's main radio receiver appears to have failed, and the backup receiver may have a faulty tracking loop capacitor which might make communications with the beleaguered ship extremely sensitive.

On April 5, the computer command subsystem entered a protection sequence which switched the craft from the primary receiver to the secondary receiver since no command had been received in seven days. Attempts to attain two-way lock on the secondary receiver failed and diagnostic tests executed after the switch to this unit indicated a problem with its tracking loop capacitor. The protection sequence is programmed to switch back to the primary receiver if the secondary unit receives no commands in the following twelve hours. Since attempts to attain two-way lock on the second receiver failed, the program switched back to the main receiver.

After this switch, operations appeared normal and several commands were transmitted through the main receiver, thus causing a reset of the seven-day timer. However, about 30 minutes after the switch, an unknown failure in the receiver caused excessive current which appears to have blown the receiver fuses.

The spacecraft remains configured on the main receiver and unable to receive commands from Earth. However, the seven-day timer will automatically switch to the secondary receiver on April 13, at which time attempts will be made to command the spacecraft in spite of the failed capacitor.

Normal navigation has depended on two-way Doppler, but the receiver failures will probably necessitate use of alternate navigation techniques.

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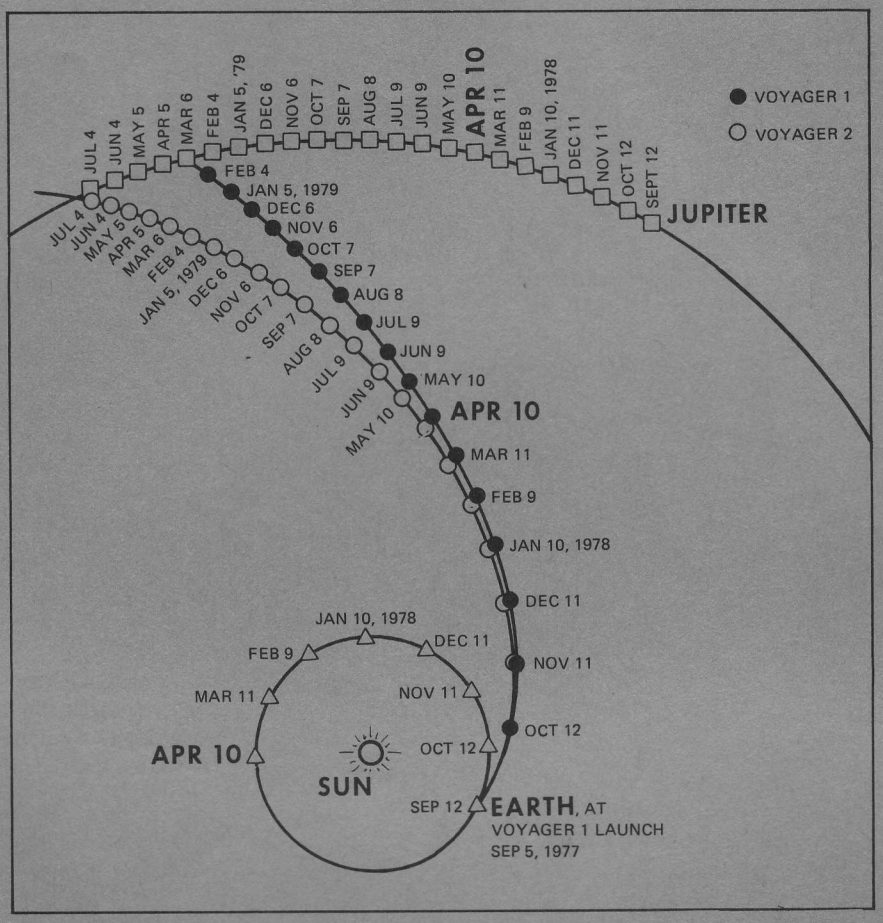
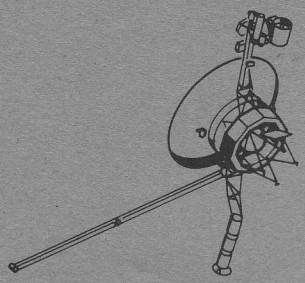


HALFWAY THERE. Both spacecraft are now closer to Jupiter than to Earth. As of April 10, Voyager 1 will be nearly 482 million kilometers (299 million miles) from Earth and 343 million kilometers (213 million miles) from Jupiter, targeted for closest approach on March 5, 1979. Voyager 2 will be 465 million kilometers (289 million miles) from Earth and 360 million kilometers (223 million miles) from Jupiter on April 10, headed for a July 9, 1979 rendezvous.



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VOYAGER

April 13, 1978 **No. 19**

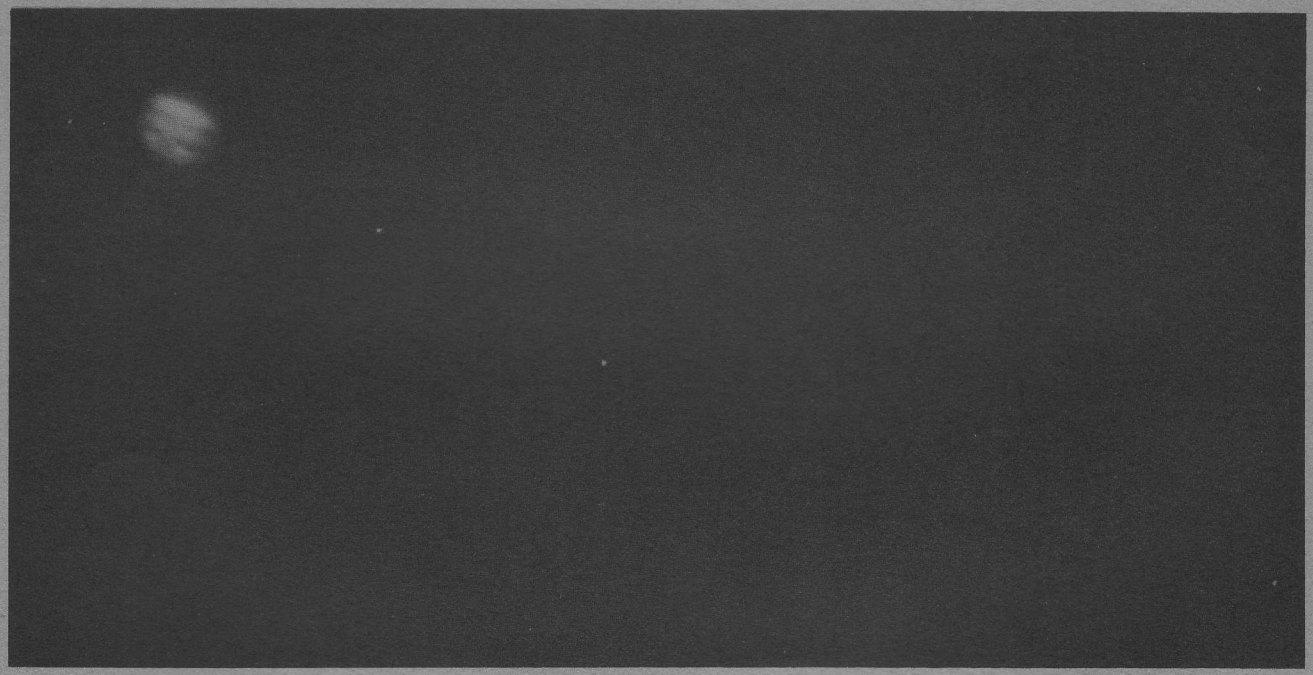
VOYAGER 2 REESTABLISHES COMMUNICATIONS

Voyager 2 was successfully commanded early Thursday morning using previously untried techniques, after more than a week of radio problems.

Shortly after 3:30 a.m. (PST) Voyager operations sent the first command to the spacecraft through the Madrid tracking station. Just before 4:30 a.m., controllers received confirmation that the command had been received and accepted. It took almost 27 minutes for the command, travelling at the speed of light, to reach the spacecraft, and another 27 minutes for the return flight of the command acknowledgement to reach Earth.

Voyager 2's week-long emergency began April 5 when the backup receiver showed evidence that it was having trouble accepting commands and the spacecraft's primary radio receiver failed. In the event the spacecraft does not receive a command for seven days, it automatically switches to the redundant receiver. That seven-day period was up early Thursday morning, thus allowing a 9-hour sequence of commands to be sent to Voyager 2.

The apparent failure of the backup receiver's tracking loop capacitor means that the receiver can no longer normally follow a changing signal frequency. The difficulty in this is that signals from Earth change in frequency due primarily to



BY JOVE, IT'S JUPITER! This photograph of Jupiter and its four Galilean satellites was taken by Voyager 2 on February 8, 1978, when the spacecraft was 437 million kilometers (271.5 million miles) from the planet. The picture was taken by Voyager 2's narrow-angle camera through a blue filter. North is toward the top with the satellite Europa at left. Io, Ganymede and Callisto, in that order, range outward from the planet to the right. The fuzzy spot in Jupiter's southern hemisphere is not the Great Red Spot, but a reseau mark on the imaging system that was removed by the Image Processing Lab (IPL) at the Jet Propulsion Laboratory (JPL). The Galilean satellites are much dimmer than Jupiter, so the IPL increased their brightness by computer enhancement to make the planet and satellites equally visible. When this image was taken, Voyager 2 was threading its way through the asteroid belt between Mars and Jupiter, and had almost 1-1/2 years of cruise left before it reaches Jupiter in July 1979. The Voyager project is managed for NASA by JPL, California Institute of Technology.

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the doppler effect caused by Earth's rotation. Therefore, spacecraft engineers must determine the frequency at which the receiver is listening, and then compute the frequency at which the Deep Space Station must transmit to send a command.

The doppler effect can be observed by standing, for example, near a railroad crossing and observing an approaching train. As the train approaches, the pitch of its horn (and thus the observed frequency) rises until it passes the observer, and then falls to a lower pitch as the train disappears in the other direction.

The first command sent after Voyager 2 switched to its backup receiver today was transmitted over a rising frequency range, as controllers attempted to determine the frequency to which the receiver is tuned. Later commands zeroed in on this frequency. Commands were sent to prevent turn-on of the X-band transmitter in an effort to prevent temperature changes which could affect the frequency, to prevent switching to the high-gain antenna since it was during such a switch a week ago that the primary receiver failure appeared, and to turn the S-band transmitter to high power so that the spacecraft can be tracked by the 26-meter (85-foot) antennas of the Deep Space Network.

Since the spacecraft emergency was declared a week ago, Voyager 2 has been tracked continuously by the gargantuan 64-meter (210-foot) antennas of the DSN. This has been accomplished with the cooperation of the Viking, Pioneer, and Helios projects which are also tracked by the DSN. Only the 64-meter antennas can receive the S-band low power signals which the spacecraft has been transmitting the past week.

Mission officials are highly optimistic that Voyager 2 will be able to achieve its objectives.

The next automatic cruise sequence is scheduled to be sent to the spacecraft on April 27. It includes Voyager 2's second trajectory correction maneuver (TCM), scheduled for May 3. Further investigation is needed to determine whether this load can and should be transmitted. As a minimum, commands to maintain the high-gain antenna pointed at the Earth, which is essential for communications with the spacecraft, will be transmitted.

VOYAGER 1 QUIET

Activity on Voyager 1 has been quiet as all effort has been concentrated on its sister ship. The photopolarimeter instrument has been turned off as the analyzer wheel is apparently stuck in a manner similar to Voyager 2's, which has been freed.

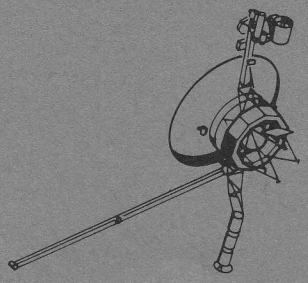
SUMMARY

Both spacecraft are nearing the center of the asteroid belt which lies between the orbits of Mars and Jupiter.

Voyager 2, travelling at about 19.7 kilometers (12.2 miles) per second relative to the Sun, is more than 474 million kilometers (294 million miles) from Earth, at about 2.8 AU from the Sun. One-way signal time is 26 minutes 16 seconds.
Sun and the Earth, and equals about 150 million kilometers or 93 million miles), and Jupiter's orbit lies ahead at about 5.2 AU. One-way communication time with Voyager 1 is 27 minutes 13 seconds.

Voyager 2, travelling at about 19.7 kilometers (12.2 miles) per second relative to the Sun, is more than 474 million kilometers (294 million miles) from Earth, at about 2.8 AU from the Sun. One-way signal time is 26 minutes 16 seconds.

The spacecraft velocities will continue to decrease as they move further into space, as the effect of the Centaur/Propulsion Module boost shortly after launch is gradually overpowered by the gravitational pull of the Sun.



MISSION STATUS BULLETIN

VOYAGER

MAY 4, 1978 **No. 20**

SUMMARY

Eight months after launch and eight months before beginning close Jupiter observations, Voyager 1 is nearly 555 million kilometers (348 million miles) from Earth, at a distance from the Sun of about 3.1 AU. Its velocity relative to the Sun is about 19.9 kilometers (12.4 miles) per second, and one-way communication time is 30 minutes 45 seconds.

On May 3, Voyager 2 successfully performed a mid-course correction maneuver to adjust its Jupiter-bound trajectory. The maneuver was included in a set of commands successfully relayed to the craft on April 26. Voyager 2 is nearly 535 million kilometers (332 million miles) from Earth, or about 3.0 AU from the Sun. Its velocity relative to the Sun is about 18.8 kilometers (11.7 miles) per second, and one-way communication time is 29 minutes 52 seconds. Voyager 2 began its journey about 8-1/2 months ago, and will begin Jupiter observations in about 11-1/2 months.

UPDATE

VOYAGER 1

A plausible model for the Voyager 1 scan platform sticking has been developed and is now being tested. The possible explanation for the sticking involves a small piece of plastic from the scan actuator fill screw locking mechanism resting on one or two teeth of the actuator's final gear. Before the Voyager 1 platform is again moved into the region where it previously stuck, laboratory tests will be conducted to determine the effects of the modeled failure.

The Voyager 1 S-band solid state amplifier (SSA), operating in its high power mode, is beginning to exhibit degradation characteristics similar to those previously seen on Voyager 2. The switch to the S-band traveling wave tube (TWT) amplifier was accomplished on May 10.

VOYAGER 2

On April 26, a regular load of the Voyager 2 CCS computer was accomplished. This load contained the sequence to perform a trajectory correction maneuver on May 3. What made this load unique was that it was performed flawlessly, using new techniques developed to command the spacecraft in spite of its one remaining crippled receiver. These techniques involve predicting the rest frequency of the spacecraft's voltage controlled oscillator (VCO), and programming the ground-transmitted frequency to match it within about 50 Hz. It is fortunate that the 64-meter Deep Space Stations have the ability to program the uplink frequency, a capability not previously planned for Voyager operations; the same capability is now being planned for all stations.

TCM B2 on May 3 involved a 203-second burn with a .615 m/sec velocity change. Early indications show a nominal maneuver with no problems.

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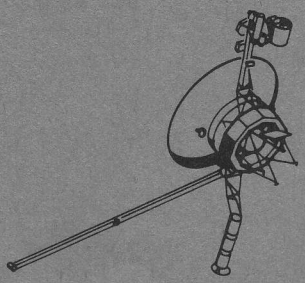

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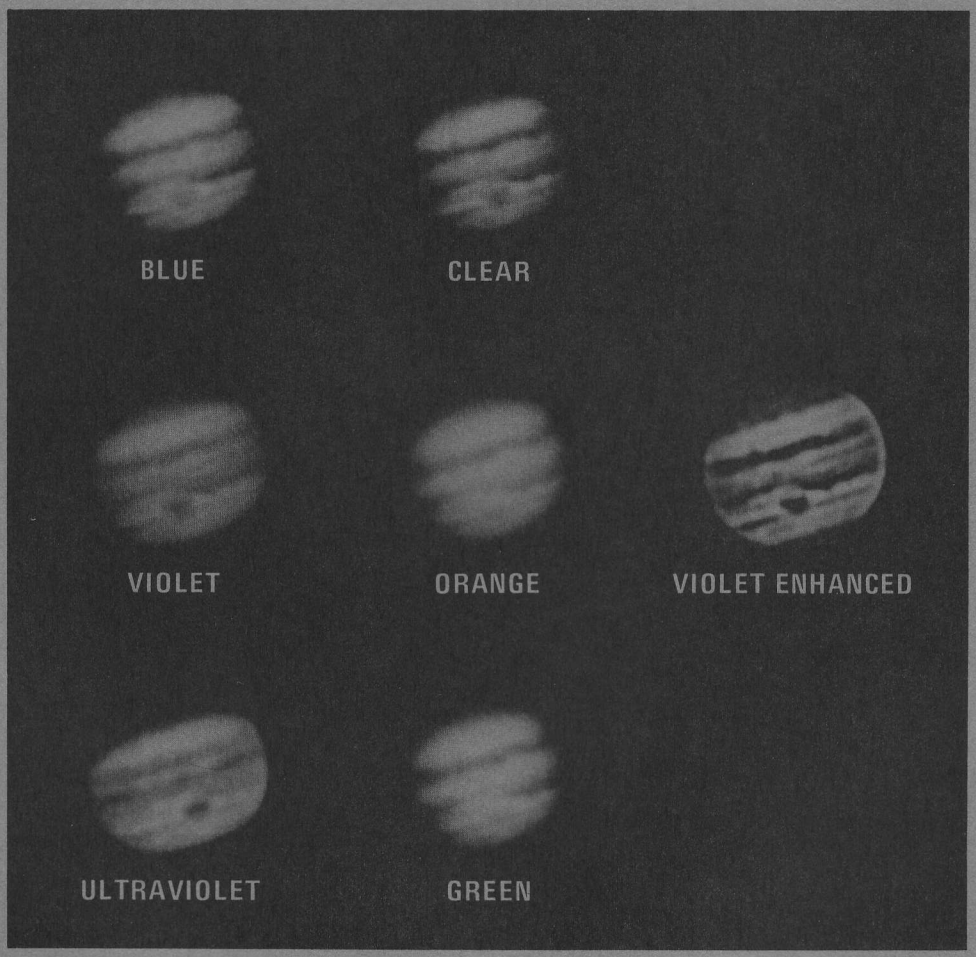
VOYAGER

June 27, 1978 **No. 21**



VOYAGER 1 took these narrow-angle pictures of Jupiter on May 19 from a distance of 295 million kilometers (183 million miles or about 2 AU). The original image scale is 2900 kilometers/pixel, still poorer than the best Earth-based photography. Of the original sixteen narrow-angle images, taken during a twenty-five minute interval, the Image Processing Laboratory (IPL) at JPL has chosen six, one in each color, to present in this illustration. The six have been digitally enlarged and increased in contrast by the IPL. The seventh frame is a version of the violet image, which has been spatially filtered to specially enhance the smallest details. Notice that Jupiter's Great Red Spot is prominent in pictures taken at short wavelengths (ultraviolet, violet, and blue) but is not clearly visible in longer wavelength (green and orange) images. Almost ten months of Earth-to-Jupiter cruise remained on May 19.

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SUMMARY

Voyager 1 is about 679 million kilometers (422 million miles or about 4-1/2 AU) distant from Earth, travelling with a heliocentric velocity of 18 kilometers (11 miles) per second. One-way communication time is 37 minutes 42 seconds.

Travelling with a heliocentric velocity of 17 kilometers (10.5 miles) per second, Voyager 2 is 651 million kilometers (405 million miles or about 4-1/3 AU) from Earth. One-way light time has stretched to 36 minutes 10 seconds.

UPDATE

VOYAGER 1

Scan Platform

Constraints on Voyager 1's scan platform slewing envelope have been removed following successful in-flight testing.

Tests on three consecutive days (May 31 through June 2) moved the platform through the area in which the platform hung up in February, with no hangup in the area of concern, below 60° azimuth.

Previous tests in March and April, which avoided the problem area, indicated no problems in moving the platform through other regions.

In the latest test, azimuth axis motion was evaluated over the range of 345° to 10°, and particularly from 53° to 31°. No irregularities were found other than possible slowdown at higher azimuth angles, which is still being analyzed.

Plasma Instrument

Voyager 1's plasma instrument is operating normally again following a series of tests in mid-May.

The sensitivity of the main detector dropped significantly on February 17. Analysis of the problem indicated an open circuit in an amplifier, and a series of heating and cooling tests was planned in an effort to restore contact.

On May 16, the replacement heater was turned on, raising the temperature of both the modulator and the electronics, but no change in science data was observed at that time and the heater was turned off.

However, minutes prior to the start of the cooling test on May 18, which would have turned off all heaters, data indicated that the instrument was operating properly, and the cooling test was cancelled pending further analysis.

The instrument has been returning good science data since that time.

Pitch Thruster Test

A test of the pitch thruster impingement was conducted on Voyager 1 on June 15.

The test provided data to refine comparisons of calculated versus observed impingement values. Voyager 1's first trajectory correction maneuver last fall indicated that a portion of the exhaust gas from the thrusters is impeded by a bus support structure. This reduces the desired velocity changes.

In this test, the spacecraft's high gain antenna was turned 45° off Earth point in either direction to fire first one and then the other pitch thruster while pointing at the Earth. The thrusters are mounted at a 45° angle on either side of the high gain antenna.

All signals but the wide carrier signal were turned off and Earth receivers were focussed in on the high gain antenna to track the resulting doppler effect. In a few months, the spacecraft-to-Earth distance will be too great to capture the signal with the high-gain antenna pointed that far off the Earth line.

Analysis of the test results is continuing and will be factored into calculations for future maneuvers.

VOYAGER 2

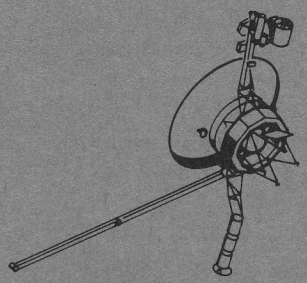
Backup Mission Load

A backup mission sequence was relayed to Voyager 2 on June 23. This computer program is designed to ensure at least a minimum mission return should communications be lost through failure of the remaining receiver sometime in the future.

Voyager 2's primary receiver failed on April 5, leaving the spacecraft with only one receiver and no recourse should that one fail. Early probe missions were equipped with only one receiver and carried backup sequences as safeguards.

The sequence will be stored in the backup computer command subsystem. It includes operation of all 11 experiments, including imaging at Saturn but not at Jupiter. The scan platform would move through three positions per planet, as compared to the thousands of positions it would assume in the normal mission.

The load also includes one trajectory correction to retarget to Saturn after Jupiter encounter in July 1979.



MISSION STATUS BULLETIN

VOYAGER

July 25, 1978 **No.22**

SUMMARY

Both spacecraft continue their interplanetary cruises, with periodic calibrations and tests. The gap between them is widening, as the data clearly show:

July 25, 1978	*Voyager 1*	*Voyager 2*
Distance from Earth, km	*~ 714 million*	*~ 683 million*
Distance from Earth, mi	*~ 444 million*	*~ 425 million*
Distance from Earth, AU (1 AU = 150 million km or 93 million mi)	*~ 4.7*	*~ 4.5*
Heliocentric velocity	*17 km/sec (10.5 mi/sec)*	*16 km/sec (10 mi/sec)*
One-way light time	*39 min 40 sec*	*37 min 59 sec*
Launch Date	*September 5, 1977*	*August 20, 1977*
Jupiter Encounter Date (closest approach)	*March 5, 1979*	*July 9, 1979*

UPDATE

Solar Conjunction

Voyagers 1 and 2 took a brief rest this month as the Earth and spacecraft moved into solar conjunction. For a period of about two weeks for each spacecraft, the Sun-Earth-Probe (SEP) angle was less than ± 5 degrees, and no commands which would change the state of the spacecraft were allowed.

Due to the position of the Sun between the Earth and the spacecraft, data reception was "ratty" during this period. Voyager 2 moved out of solar conjunction on July 24.

Voyager's solar conjunction happened to occur during the largest solar flare activity observed in recent years.

AACS Patch

In mid-August, several refinements will be made to the attitude and articulation control subsystem (AACS) of both spacecraft.

One change will compensate for rate changes induced by movement of the digital tape recorder (DTR). These rate changes, although slight, are still enough to cause smear in the imaging. The AACS will now automaticallly sense when the DTR starts, stops, or reverses direction, and will pulse the attitude control jets to offset this torque.

A second patch will allow fine-tuning of the rate to position gain in the attitude control functions.

A third correction will be for gyro drift compensation. A new command will allow intentional turning of the spacecraft at a slow rate of speed, independent of the drift compensation built into the software.

In inertial control, spinning gyros provide references which, by their nature drift slightly, causing spacecraft turning. The drift can be measured and corrected. At times, however, controlled slow turning is desirable, as when even the spacecraft turn rate is too high for the ultraviolet spectrometer to track the planet limb. The new capability will allow independent control of gyro drift.

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THE VOYAGER SPACECRAFT

(This is the fifth in a planned series of brief explanatory notes on the spacecraft and its subsystems.)

Part 5 — Magnetic Fields Investigation

The magnetic field of a planet is an externally measurable indication of conditions deep within its interior. Four magnetometers aboard each Voyager will gather data on the planetary magnetic fields at Jupiter, Saturn, and possibly Uranus; the satellites of these planets; solar wind and satellite interactions with these planetary fields; and the interplanetary magnetic field.

If we are still communicating with the spacecraft when they pass beyond the orbit of Pluto and out of our solar system, the instruments may beam back news of the interstellar medium as well.

Voyager's fields and particles investigations, of which the magnetic fields experiment is one, are complementary, having overlapping areas of study but each with its own unique methods of observing and reporting on the same phenomena.

Solar Wind and Magnetospheres

The magnetometers will reveal a great deal about the interplanetary medium — the thinly scattered ionized and magnetized gas within the spaces of our solar system — which forms the solar wind.

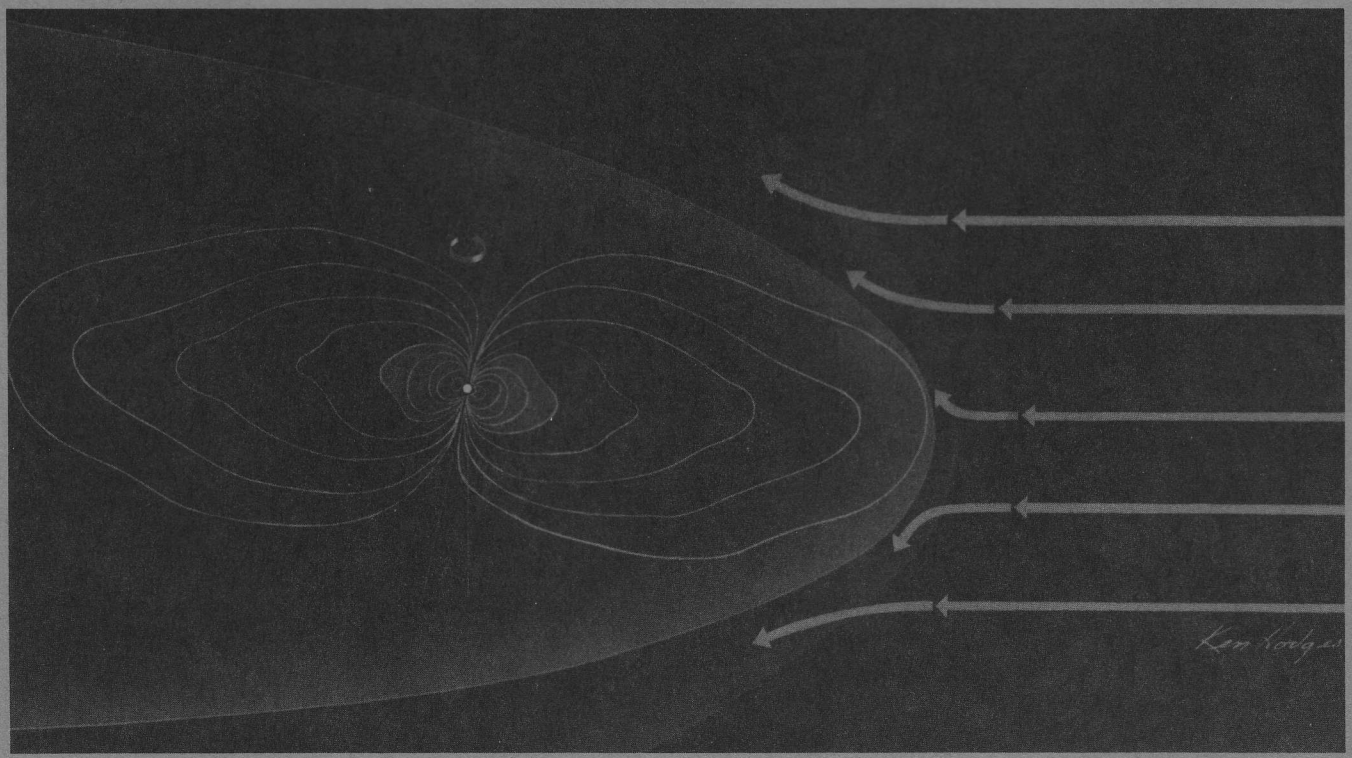
Our Sun is constantly emitting electrically-charged particles, mostly protons and electrons, from the ionization of hydrogen. This gas is in the fourth state of matter called a very high "plasma" (the other three states are solid, liquid and gas). It travels at speeds varying from 300 to 1100 kilometers (185 to 685 miles) per second. Although of extremely low density (less than 100 particles per cubic centimeter), the plasma permeates all of interplanetary space and forms the solar wind. Because of its ionized state, it is an electrically-conducting medium in interplanetary space.

The solar wind is deflected by planetary magnetic fields and streams around the obstacle, confining the planet's magnetic field to a limited region of space called the magnetosphere. At Earth, the magnetosphere is a long, narrow tail on the far side of the planet (away from the Sun). The ion tails of comets (but not the dust tails) also stream in the direction of the solar wind flow.

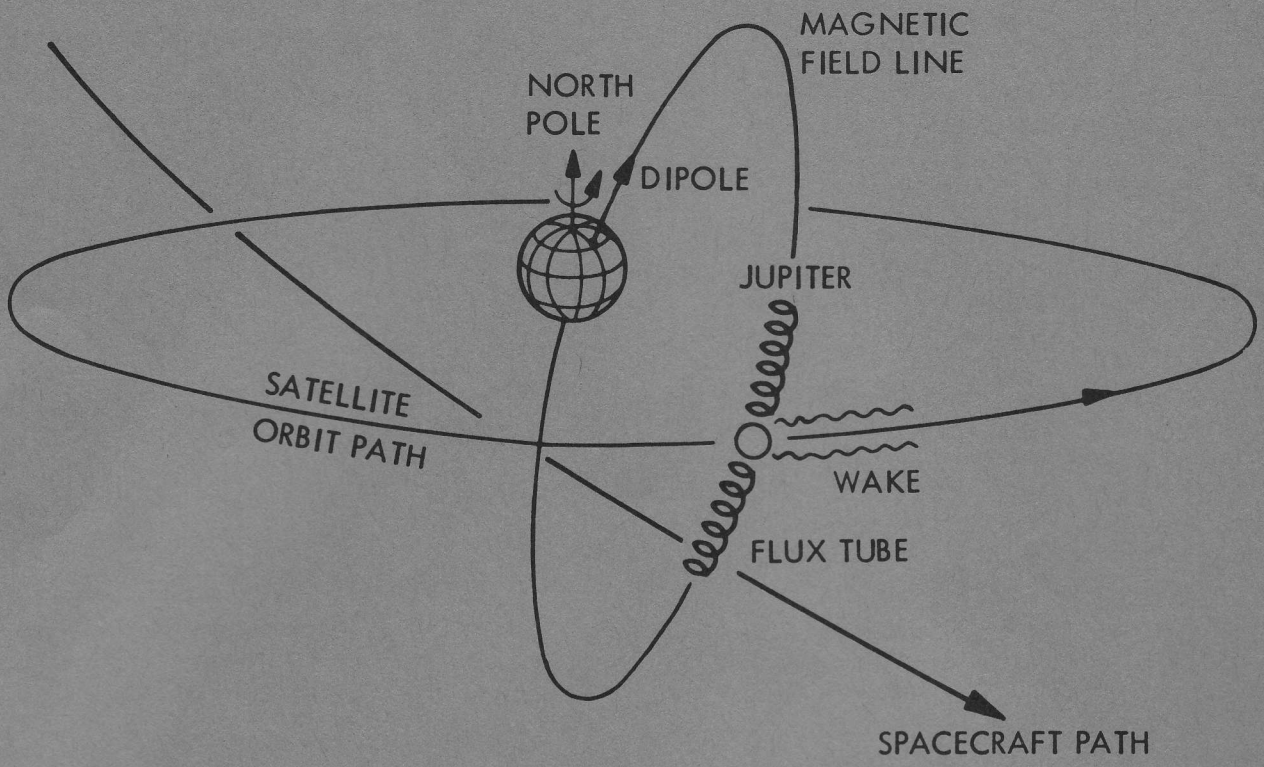
Well past the orbit of Uranus (at 20 AU), Voyager will be alert to detect the outer edge of the solar wind, although this may be as far distant as 50 AU (7-1/2 billion kilometers or 4-3/4 billion miles), well beyond the nominal limits of the mission.

The three-dimensional shape of Jupiter's magnetosphere is not well understood. The timing of the Voyager arrivals at Jupiter, four months apart, will allow concurrent measurements of the interplanetary medium near Jupiter and the Jovian magnetosphere itself. Thus, changes in characteristics of the magnetosphere can be identified as true spatial variations or as temporal ones induced by changes in the interplanetary medium.

Jupiter's rapid rotation rate (1 Jovian day is about 10 Earth hours) may be a cause of the strongly distorted



SOLAR WIND — The outer, least dense region of the Jovian magnetosphere (left) is highly variable in size, perhaps due to varying pressure of the impinging solar wind (right).



JUPITER FLUX TUBE AND IO WAKE – The motion of a Galilean satellite through the Jovian environment can produce such interesting geometrical regions as a "flux tube", where the satellite interrupts the flow of charged particles along the magnetic field lines, and a "wake" region, which arises from the satellite interference with the co-rotating planetary plasma.

outer magnetosphere. At large distances from the planet, the magnetic field lines appear to form a spiral structure, which might be explained by outward plasma flow.

The interaction between a satellite and the Jovian magnetosphere depends on the properties of the satellite and its ionosphere, on the characteristics of the field and particle environment, and on the properties of the Jovian ionosphere.

The Jovian magnetosphere rotates with the planet, extending as far as the orbit of Callisto, the fourth Galilean satellite of Jupiter.

Io Interaction

A strong factor in choosing the spacecraft flight paths was the desire to observe a special region of interaction between Jupiter and its satellite Io, known as the flux tube. The flux tube is defined by the magnetic lines of force of Jupiter which pass through Io, and is roughly a banana shape.

Voyager 1 is targeted to pass through the flux tube at a distance of 25,000 kilometers (15,500 miles) from Io, and should return a definitive observation of the interaction. The spacecraft will spend a maximum of 4-1/2 minutes in the flux tube.

Decametric radio wave noise bursts (4 to 40 kilo-Hertz) from Jupiter are a puzzling phenomena which are probably connected with plasma instabilities within the Jovian ionosphere. The satellite Io appears to exert some influence on these radio emissions through its magnetic flux tube, which intersects both the plasma around Io and the Jovian ionosphere.

Io is thought to have no internal magnetic field, although its rocky surface, and that of Europa, should have some magnetizable material. Io is known to have an atmosphere and to be a source of sodium.

Saturn and Titan

Saturn may also have a magnetic field and magnetosphere similar to Jupiter's, but its magnetic field is expected to be somewhat weaker. There is no large satellite like Io close to Saturn. The major Saturnian satellite to be studied by Voyager, Titan, is more than 1 million kilometers (620 thousand miles) from the planet and may or may not be inside the planet's magnetosphere.

Titan is larger and more massive than Earth's Moon and has a gravitationally-bound atmosphere. Study of Titan will be of special significance, and Voyager 2 may have an opportunity to measure Titan's "wake" as the satellite moves through the solar wind or the Saturnian magnetosphere.

If the Uranus flyby option is realized, a "pole-on" probe of the Uranian magnetosphere may be possible, since the axis of Uranus points almost toward the Sun. The magnetosphere appears to include the orbit of the satellite Oberon.

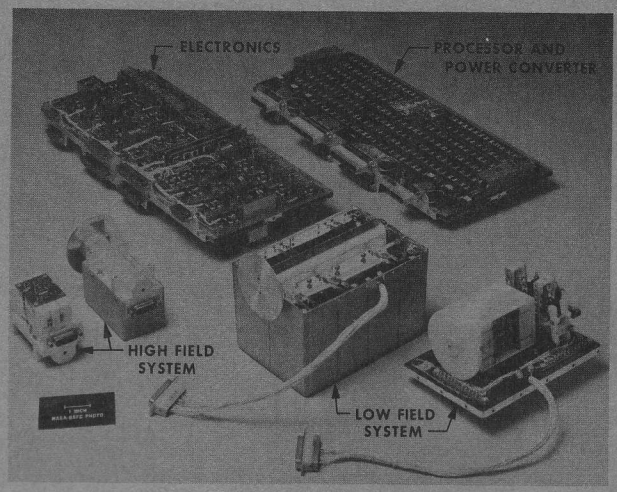
Instrument Package

Each spacecraft carries dual magnetometers to provide simultaneous data and eliminate from the measurements the small but increasingly important magnetic field of the spacecraft itself.

Since a wide, dynamic measurement range is required to meet the planetary and interplanetary objectives, the experiment uses both a low-field and a high-field system. Each system contains two identical triaxial fluxgate magnetometers. The low-field system will be operated alone during cruise, measuring the interplanetary medium in eight ranges from about 0.002 gamma to 1/2 Gauss (the Earth's field at the surface is about 1/2 Gauss). Both systems will operate during encounter periods.

To isolate the low-field magnetometers from the spacecraft's own magnetic field as much as possible, the instruments are located on a 13-meter (43-foot) boom which was carefully packed into an aluminum canister during the launch phase and then extended out to its full length during the parking orbit. This "Astromast" type of boom is indeed an engineering achievement and the longest boom for such purposes ever flown.

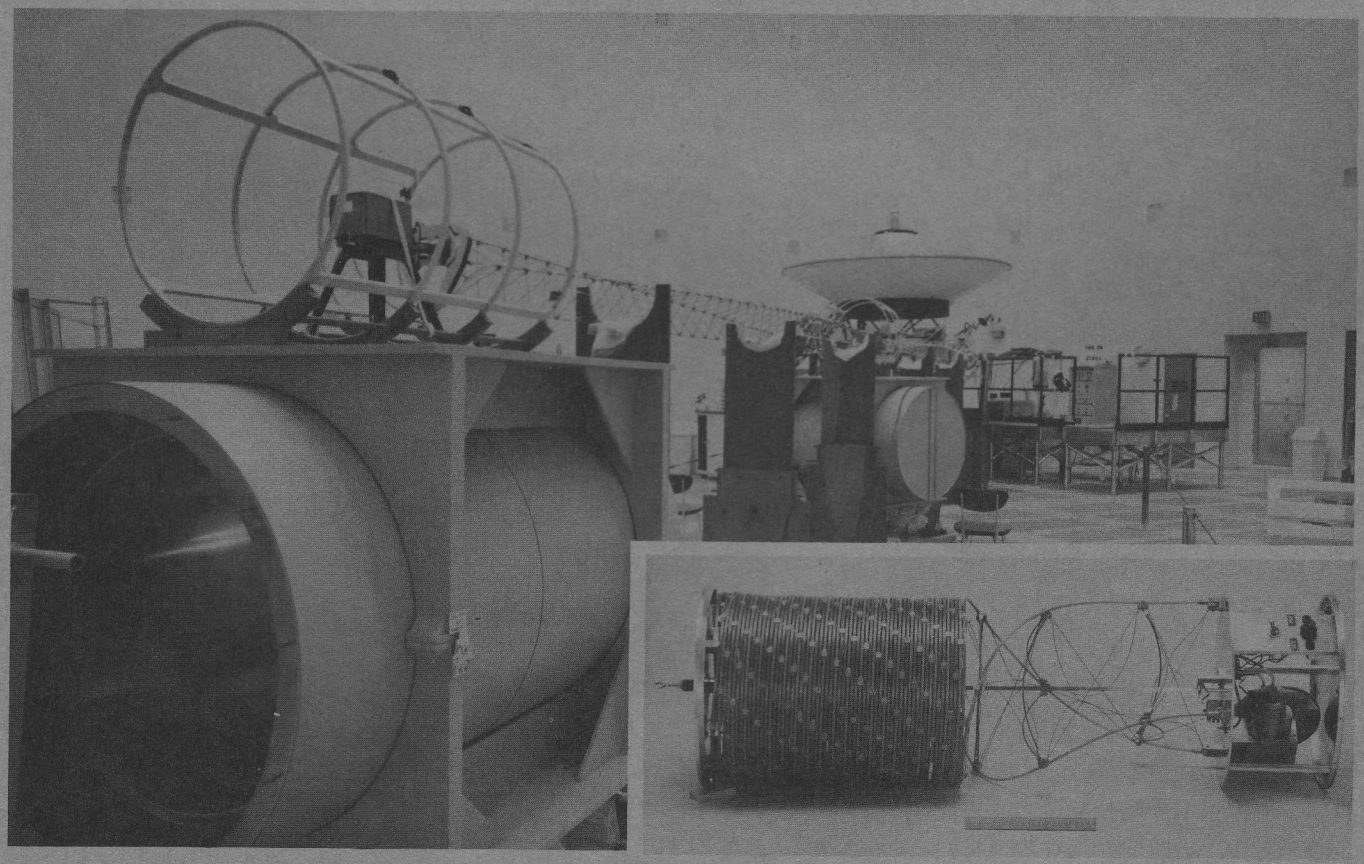
One low-field sensor is perched at the tip of the boom, while the other is stationed at about the mid-



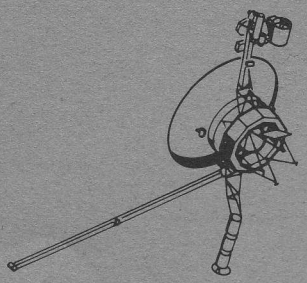
point. The high-field sensors are located nearer the spacecraft bus, on the boom's support structure.

With the addition of the electronics, the total experiment weight is 5.6 kilograms (12 pounds) and the maximum power requirement is 2.2 watts.

Principal investigator for the experiment is Dr. Norman Ness of the Laboratory for Extraterrestrial Physics at NASA's Goddard Space Flight Center (GSFC), Greenbelt, Maryland. Co-investigators include Drs. M. H. Acuna, K. W. Behannon, L. F. Burlaga, and R. P. Lepping, all at GSFC, and F. M. Neubauer at the *Institut für Geophysik und Meterologie, Technische Universität*, Braunschweg, Federal Republic of Germany.



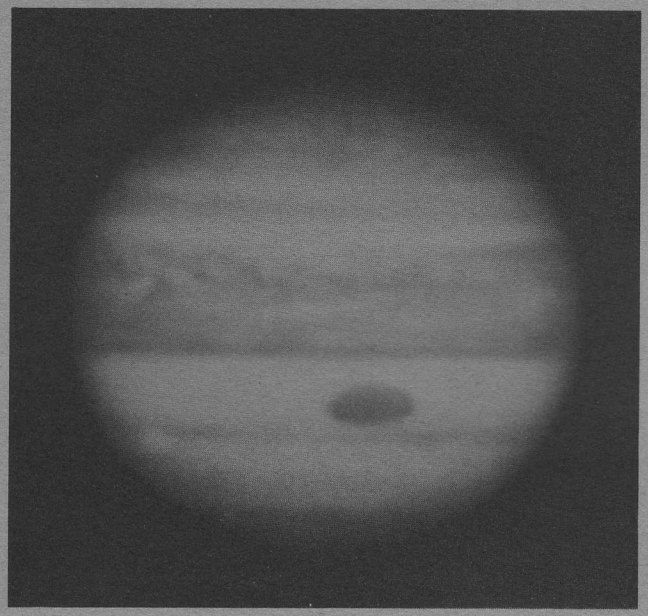
"ASTROMAST" – Voyager's 13-meter-long (43-foot) magnetometer boom is fully extended during a test setup in JPL's Spacecraft Assembly Facility. Before launch, the boom was compactly stored in a 41-centimeter-long (16-inch) aluminum canister (inset). The one-G pull of Earth's gravity requires the use of supporting structures seen in this photo. The cylindrical fixtures are flux tanks.



MISSION STATUS BULLETIN

VOYAGER

September 5, 1978 **No. 23**



ATMOSPHERIC CHANGES AT JUPITER. These photos, one ground-based and one from Voyager 1, show the dramatic changes in the giant planet's dynamic atmosphere in four years. The composite photograph on the left was taken August 18, 1974 with a 155-centimeter (5-foot) reflecting telescope at the Catalina Observatory, Lunar and Planetary Laboratory, University of Arizona-Tucson. Note the broad, bright band in the southern hemispheric area of the Great Red Spot. The photo on the right was taken with a violet filter on May 19, 1978, by Voyager 1's narrow angle camera, at a distance of 295 million kilometers. (The narrow angle aperture size is about 19 centimeters, focal length is 1500 millimeters.) The Great Red Spot is now surrounded by only a narrow bright band, flanked by darker bands above and below it, while the broadest bright band is now in the northern hemisphere. Some Jupiter observations will be retargeted toward the northern hemisphere to look more closely at the bright band. Red Spot observations will not be affected by these changes.

SUMMARY

On September 5, one year after its launch, Voyager 1 is 723 million kilometers (449 million miles) from Earth, travelling with a heliocentric velocity of 16 kilometers per second (38,555 miles per hour). The arc (total) distance travelled at this point is 781 million kilometers (485 million miles). Jupiter lies 179 million kilometers (110 million miles) off the starboard bow, at about 5.2 AU*. Voyager 1 is at about 4.07 AU, and one-way light time is 40 minutes 11 seconds.

On the first anniversary of its launch, August 20, Voyager 2 was 693 million kilometers (431 million miles) from Earth, travelling with a heliocentric velocity of 15.2 kilometers per second (34,058 miles per hour). The arc (total) distance travelled at that point was 778 million kilometers (484 million miles). Jupiter was 234 million kilometers (146 million miles) distant. At 3.7 AU from the Sun, one-way light time to Voyager 2 is 39 minutes 33 seconds.

*1 AU (astronomical unit) is the average distance between the Sun and the Earth, about 150 million kilometers (93 million miles).

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ONE YEAR IN SPACE...

It has been a full year since the Voyagers set off to explore the cosmic ocean, and while the sailing has not always been smooth, the ships are currently healthy and functioning well.

It has been a busy cruise phase. Several instruments aboard Voyager 1 have already made contact with the first major island – Jupiter – while others continue to sample the interplanetary medium. The imaging system has returned several series of good resolution photographs of Jupiter and various stars, and the planetary radio astronomy (PRA) experiment has "sighted" the giant planet in its radio spectrum noise.

As a sidelight, one experiment, the plasma wave subsystem (PWS), has even sent us sounds of the spacecraft itself. The PWS measures waves of charged particles moving in space, and records data in several ranges, including the audio range from about 15 Hz to 20 kHz. When the spacecraft's thrusters fire, the hydrazine gas is decomposed by a catalyst, and expelled into space. The addition of this matter to the relatively low-density local area of the spacecraft is recorded by the PWS, and when the data is played at an audio frequency, the sound is somewhat like a 5-gallon can being hit with a leather-wrapped mallet.

Calibrations

The major tasks of the months of cruise, however, have been the numerous tests and calibrations, all aimed at assuring the best possible science return from the Encounter periods. The experimenters need to know the engineering parameters dealing with various measurements, to aid later data interpretation. For the scan platform instruments, they need to know the sensitivity variation across each instrument's field-of-view (FOV), and the exact pointing position of each instrument relative to the others to determine the amount of overlap in their fields-of-view. This latter point is particularly important to determine the region of space or surface of the planet seen by each instrument relative to the others, so data from the various instruments can be correlated.

Accurate pointing information is particularly important for the ultraviolet spectrometer (UVS) in which the viewing slit is only 0.3 degrees – leaving little margin for error. The UVS will view the Sun as it sets behind the disks of Jupiter and Saturn, measuring the atmospheric gases. These solar occultations are high-priority goals of the mission.

Intensity calibrations are also important tasks for the UVS and photopolarimeter (PPS) to determine if their sensitivities remain at pre-launch laboratory test levels.

Scan Platform

All constraints on Voyager 1's scan platform slewing were removed after testing in late May-early June found no irregularities in moving through the area in which the platform hung up in late February.

The suspected cause of that problem is debris, initially found in the output gear and subsequently in the second last gear. It is believed that the debris has been crushed by the gears, and no further difficulty is expected.

The debris appeared to consist of soft, compliant material pieces which could have come from several sources during assembly of the unit.

AACS Patch

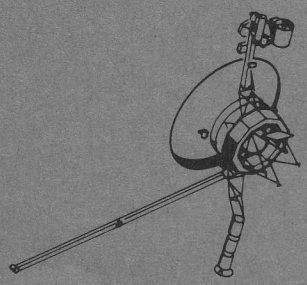
Both spacecraft have now had their attitude and articulation control subsystem (AACS) software modified. The changes, sent August 14 to Voyager 1 and August 28 to Voyager 2, include automatic thruster compensation for rate changes induced by the digital tape recorder starts and stops, the ability to fine-tune the rate to position gain, and the ability to independently command gyro drift turns.

Propellant Consumption

Propellant consumption continues to be closely monitored, as Voyager's sailors learn the appetite of the spacecraft. Increased hydrazine usage can be expected during maneuvers and tests involving the thrusters, AACS, and trajectory corrections. Actual data from past maneuvers are being used for budget planning for the mission.

Of an initial 105 kilograms (232 pounds), Voyager 1 has used almost 13 kilograms (29 pounds) of hydrazine in the past year, with about 92 kilograms (203 pounds) remaining. About 6.4 kilograms (12 pounds) of fuel is expected to be used from the start of Jupiter observations on January 4, 1979 through the end of the first encounter on April 9, 1979. Eighty percent of the hydrazine usage during the 39 hours of the near encounter phase on March 5 will be to compensate for slews of the science platform, as the craft swivels its instruments frequently to alternate views of Jupiter and the Galilean satellites.

Voyager 2 has used about 10 percent of its propellant, or about 11 kilograms (24 pounds). Ninety-four kilograms (207 pounds) remain.



MISSION STATUS BULLETIN

VOYAGER

October 2, 1978 **No. 24**

Mission Highlights

Voyager 1 Clears Asteroid Belt; Voyager 2 Close Behind

Voyager 1 successfully cleared the area of the asteroid belt on September 8, 1978, and Voyager 2 will complete its passage on October 21.

The asteroid belt is a band of rocks and dust 360 million kilometers (223 million miles) wide between the orbits of Mars and Jupiter; its inner edge begins about 105 million kilometers (65 million miles) from Earth's orbit.

Both spacecraft entered the asteroid belt on December 10, 1977, Voyager 1 trailing a few hours behind Voyager 2. Voyager 1, launched after Voyager 2, has been flying a faster trajectory, and has been steadily pulling ahead of its companion since overtaking it last December 15.

Mark III Command System Implemented

On September 15, operations switched over to the Mark III ground data system (GDS), with elements in both the Deep Space Network (DSN) and JPL's Mission Control and Computing Center (MCCC). It includes a new command system using minicomputers rather than the IBM 360/75 computer. The 360/75 computers are still used for data records. In addition to providing the new store and forward command system, the Mark III GDS includes new data switching, and ground data error correction capability. New operations control and ground data system monitoring capabilities are provided to simplify operations.

Update

Voyager 1

Capability Demonstration Tests

Also included in Voyager 1's busy month was the first of three important capability demonstration tests, designed to test spacecraft and ground system alike under encounter conditions. All went smoothly, with only minor software problems.

The first test, conducted on September 26 and 27, consisted of three parts. Part 1 required execution of the entire near encounter sequence from Jupiter minus 24 hours to Jupiter minus 14 hours 50 minutes. The ten-hour test began at 4 a.m. PDT when the spacecraft was in view of Deep Space Station 14 (64-meter antenna) at Goldstone, California.

Part 2 of the test excercised several imaging modes planned for contingency or backup during bad weather at a station. The imaging subsystem was off during this part of the test as the flight data subsystem computer tested the data rates, acquiring at least 30 minutes of data in each mode. During the test, station handover from Goldstone to Canberra was accomplished as Earth's rotation moved Goldstone out of view of the spacecraft.

Part 3 tested the capability of the Deep Space Network and MCCC to respond to multiple data rate changes with minimal data loss during such transitions. Four mode changes in 28 minutes were made. More multiple data rate tests are planned before encounter.

Cruise Science Maneuver

On September 15, Voyager 1 successfully executed a 20-hour Cruise Science Maneuver. This maneuver involves ten 360 degree yaw turns and twenty-four full roll turns, allowing routine calibration of several instruments by looking at the entire sky. The first cruise maneuver in February stopped short of completion.

Voyager 2

Stanford Communicates with PRA

On September 13, tests were conducted to examine the possibility of communicating with Voyager 2 through its planetary radio astronomy instrument as a backup to the remaining command receiver. In a five-hour test, the radio telescope at Stanford University, Palo Alto, California, transmitted in 6-minute cycles at a frequency of 46.72 MegaHertz and with a power of 300 kw. The tests showed that the PRA receiver can operate at that frequency, although the signal is weak, and that the background noise of the spacecraft is low enough that it does not cause undue interference. Further study is required, since this method of spacecraft communication would be at a much lower data rate, and require extensive spacecraft re-programming, as well as a new ground transmitting facility.

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Infrared Interferometer Spectrometer (IRIS) Warmed Up

Commands sent September 28 turned the IRIS flash-off heater on for 20 hours, temporarily raising the spectrometer temperature to 267° Kelvin. It is hoped this will interrupt or reverse any crystallization (freezing) of the motor damper and beamsplitter bonding material that may be responsible for the slow IRIS degradation observed since launch. Spectrometer temperatures have now cooled to the normal 200° K operating point and subsequent tests will determine if the short warm-up was beneficial.

After these results are analyzed, a long warm-up may be initiated. Its purpose would be to counteract stresses in the IRIS which could also have contributed to its decreased sensitivity by affecting interferometer alignment.

This is the first time the heater has been energized in space. Ordinarily, it would be used if necessary to boil off condensates accumulated in the launch phase.

Summary

Voyager 1 is about 704 million kilometers (437 million miles) from Earth, travelling at 15 kilometers per second (34,465 miles per hour) relative to the Sun. One-way light time is about 39 minutes.

Travelling at 14 kilometers per second (31,675 miles per hour), Voyager 2 is about 667 million kilometers (415 million miles) from Earth. One-way light time is about 37 minutes.

The Voyager Spacecraft

(This is the sixth in a planned series of brief explanatory notes on the spacecraft and its subsystems.)

Part 6 — Planetary Radio Astronomy

One goal of the planetary radio astronomy (PRA) experiment is to prove or disprove the existence of lightning (a catalyst for the formation of life) on the planets with atmospheres. Together with the plasma wave experiment and possibly several of the optical experiments, the PRA may be able to demonstrate the existence of lightning on Jupiter and the Saturnian satellite Titan, if indeed it does exist.

The current hypothesis is that sparks of lightning in an atmosphere of hydrogen, methane, ammonia, and water vapor (all of which appear to be present on Jupiter and Titan, as well as clouds and convection) could set off a reaction to form the complex organic molecules generally thought of as the building blocks for living systems.

Measurement Range

The PRA will measure kilometric, hectometric, and decametric planetary radio emissions in the low frequency range from 1.2 kiloHertz (kHz) to 40.5 MegaHertz (MHz). (AM radio broadcast frequencies on Earth are between 550 kHz and 1600 kHz.) Emissions ranging from wavelengths of less than 1 centimeter to thousands of meters can result from wave-particle-plasma interactions in the magnetospheres and ionospheres of the planets.

Io May Not Influence Hectometric Bursts

Io, long known to play an integral part in the pattern of Jupiter's decametric radio emissions, appears not to have anything at all to do with Jupiter's hectometric emissions, at least in the low frequency ranges. Preliminary results from study of the first six months of data show no correlation between the bursts and Io in the low frequencies. A detailed report is in preparation.

The polarization characteristics of Jupiter's radio emissions have also been defined: In the high frequencies, there is consistent right-hand circular polarization, while in the low frequencies, there is consistent left-hand circular polarization. This was an unexpected result. (To understand right- and left-hand polarization, think of a right- or left-hand screw thread or a propeller's helical motion through water.)

Terrestrial Kilometric Emissions

In the ten days following launch, the PRA had the opportunity to observe Earth's kilometric radiation while the spacecraft was transmitting at a high data rate. For the first time, Earth's polarization in the frequency range from 100 to 300 kHz was measured. This information is valuable for comparison with Jupiter data, as Jupiter's hectometric and kilometric emissions may resemble terrestrial kilometric radiation.

In addition, radio data from Jupiter, as from Earth, quite probably relate to particle precipitation, and to magnetic field strength and orientation in the polar ionosphere. This data should give some characteristics of Jupiter auroras.

Other Science Objectives

The polarization of planetary radio emissions can be used to detect the presence of planetary magnetic fields, even at great distances from a planet. PRA measurements can enable determination of planetary magnetic field strengths, to within an order of magnitude. In addition, plasma parameters near the planets such as electron density can be measured.

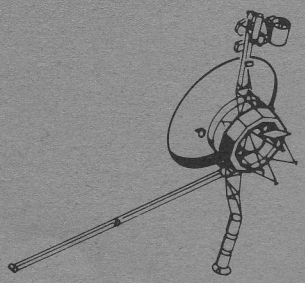
Several hundred solar flare events have been recorded by the PRA since launch in 1977, and the PRA will continue to observe solar flare activity which may be invisible on Earth.

The PRA experiment uses two 10-meter (about 33-feet) long whip monopole antennas, positioned 90 degrees apart and extending from the spacecraft bus near the joint of the radioisotope thermoelectric generator (RTG) boom. The PRA receiver provides coverage in two frequency bands — one from 1.2 kHz to 1,345 kHz, and the other from 1,228.8 kHz to 40.5 MHz.

To reduce interference from the spacecraft power supply, the receiver's local oscillator is phase-locked to the spacecraft clock to allow observations between successive harmonics of the spacecraft power subsystem.

Science Team

The PRA principal investigator is J. W. Warwick, University of Colorado, Boulder. Other team members are J. K. Alexander (Goddard Space Flight Center, Greenbelt, Maryland); André Boischot, C. C. Harvey, and Y. LeBlanc (*Observatoire de Paris*, France); W. E. Brown, Jr., S. Gulkis, and R. Phillips (Jet Propulsion Laboratory); T. D. Carr (University of Florida); F. T. Haddock (University of Michigan); J. B. Pearce, R. G. Peltzer, and A. C. Riddle (University of Colorado); and D. H. Staelin (Massachusetts Institute of Technology).



MISSION STATUS BULLETIN

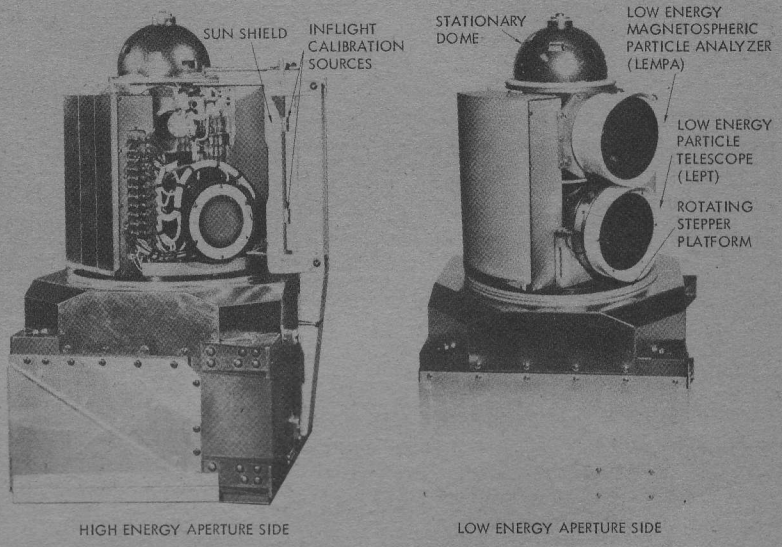
VOYAGER

October 25, 1978 **No. 25**

Summary

Voyager 1 is about 675 million kilometers (420 million miles) from Earth, travelling with a heliocentric velocity of 14.9 kilometers (9.3 miles) per second. One-way light time is 37 minutes 36 seconds. Encounter operations begin in 78 days. Encounter test and training begins October 30.

One-way light time to Voyager 2 is 35 minutes 27 seconds. The craft is nearly 637 million kilometers (396 million miles) from Earth, with a heliocentric velocity of 13.6 kilometers (8.5 miles) per second. Encounter operations are six months away.



Low-Energy Charged Particle Instrument. The LECP, located on the science boom about midway between the spacecraft bus and the scan platform, uses two detector systems to measure both planetary systems and interplanetary space.

Update

Voyager 1

Capability Demonstration Test No. 2

The second of Voyager 1's three capability demonstrations was successfully performed on October 9 and 10. Consisting of two parts, the test included execution of the early portion of the near encounter sequence and a test of the flight data subsystem's ultraviolet spectrometer autogain algorithm.

Part 1 included a test of a six-hour period just after Jupiter closest approach, when the spacecraft will pass through both the Io flux tube and Jupiter's shadow on the far side of the planet. During this period, measurements of Jupiter's atmosphere will be made as the Earth and Sun disappear behind the edge of the planet.

In Part 2, the ultraviolet spectrometer was first slewed so that the viewing slit was within 19.5 degrees of the Sun, and then swept to 19.0 degrees. The purpose of the one-hour test was to measure the response of the instrument to changing light levels while under automatic control of the flight data subsystem.

Voyager 2

IRIS Performance Improves

After a 20-hour warm-up initiated on September 28, the performance of the infrared interferometer spectrometer (IRIS) has greatly improved. The data indicate a full recovery of performance in the neon signal of the reference interferometer, and a substantial increase in the sensitivity of the infrared interferometer spectrometer to long wavelengths.

Using the flash-off heater, the instrument temperature was raised from 200° Kelvin (the normal operating point) to 267° Kelvin in an effort to reverse any crystallization of the motor damper and beamsplitter bonding material that was thought to be responsible for the slow degradation observed since launch.

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Voyager 2's IRIS will be monitored to determine if future heating will be required to maintain the improved performance.

A similar warm-up of the Voyager 1 IRIS began October 24 in an attempt to eliminate anomalies first noted in July 1978.

The Voyager Spacecraft

(This is the seventh in a planned series of brief explanatory notes on the spacecraft and its subsystems.)

Part 7 — Low-Energy Charged Particles Investigation

While Voyager 1's current speed of about 54,000 kilometers (33,000 miles) per hour far exceeds the space speed record for man*, an ion travelling at that velocity would hardly qualify as a significant energetic particle to the low-energy charged particle (LECP) experiment.

To the LECP, low-energy means particles travelling at 2400 to 28,000 kilometers (1500 to 18,000 miles) per *second*, as opposed to high-energy particles travelling at the speed of light, 300,000 kilometers (186,000 miles) per second.

The LECP investigation is a strong coupling factor in Voyager's complement of fields and particles investigations, contributing to many areas of interest, including studies of solar wind, solar flares, particle accelerations, magnetic fields, cosmic rays, and satellite surface structures.

Scientific Objectives

Two detector systems of the LECP instrument will allow measurements during both the long interplanetary cruise periods and the encounters with the planetary systems themselves. The extremely wide dynamic range, combined with wide coverage in energy and species, will allow characterization of almost all energetic particle environments Voyager traverses.

Study of the physics of planetary magnetospheres will further understanding of astrophysical objects such as pulsars and compact X-ray sources, the origin of satellites and their surface structures, and perhaps, the origin of the solar system itself.

An important task of the LECP will be to establish the morphology of the Saturnian and Uranian magnetospheres, including bow shock, magnetosheath, magnetotail, trapped radiation, and satellite-energetic particle interactions.

Observations of particle accelerations will aid in better understanding of solar flare processes, cosmic ray acceleration processes, and processes in our own magnetosphere.

Next to the Sun, Jupiter is the solar system's single most powerful radio source in the electromagnetic spectrum. The reasons for this are not well understood, but may stem from an apparent strong interaction between Jupiter's magnetosphere and the Galilean satellite Io. The Io-Jupiter interaction could be of importance in understanding other astrophysical radio sources.

Fusion research may also benefit from Voyager's probing of the trapped radiation around Jupiter. Particles in confined plasmas, forced to fuse, release an enormous energy. Clearly, Jupiter is able to confine charged particles very nicely.

Instrument Description

Located on the science boom, the LECP consists of two solid-state detector systems mounted on a rotating platform to give full-sky coverage.

The Low-Energy Magnetospheric Particle Analyzer (LEMPA) will be used primarily for magnetospheric observations near the target planets. Eight solid-state silicon sensors measure the energy and count the number of particles colliding with their surfaces. The LEMPA measures electrons in the range from about 10 kilo electron volts (keV) to 11 mega electron volts (MeV), and protons and heavier ions in the 15 keV to 150 MeV range. The dynamic range is about 1 to more than 10^{11} (nearly one trillion) particles per square centimeter per second from the entire celestial sphere, extending to 10^{13} for some of the sensors.

The Low Energy Particle Telescope (LEPT) contains fifteen solid-state detectors designed to measure the charge and energy distributions of low and medium energy nuclei in the interplanetary medium and the outer regions of planetary megnetospheres. The LEPT uses two of the thinnest detectors ever flown: 2 and 5 microns (1 inch is about 25,400 microns)! Its range is from about 0.1 to 40 MeV per nucleon, but certain modes may extend the range from 0.05 to 500 MeV per nucleon.

Both detector systems are mounted on a rotating platform which can step through a full 360° circle which is divided into eight angular sectors. Stepping rates range from 1 revolution every 48 minutes during cruise to 1 revolution every 48 seconds during encounter operations. A fixed sunshield protects the most sensitive detectors from viewing the Sun early in the mission, and serves as a high energy particle shield during traversal of the magnetosphere.

Detailed design of the LEMPA telescope and LEPT anti-coincidence detectors were done at the University of Maryland, with assembly at the Applied Physics Lab at Johns Hopkins University. The LEPT telescope was designed and built at the Applied Physics Lab.

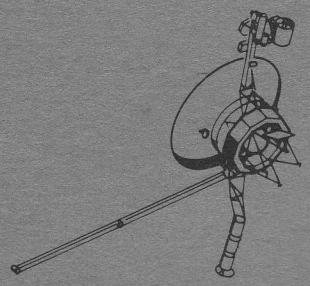
In-Flight Performance

The LECP has performed according to specifications so far, and has obtained very good data on solar flare and interplanetary particles, and Jovian electrons.

Investigators

The LECP principal investigator is S. M. Krimigis of the Applied Physics Lab (APL) at Johns Hopkins University. Co-investigators are T. P. Armstrong (University of Kansas), W. I. Axford (Max Planck Institute for Aeronomy, West Germany), C. O. Bostrom (APL), C. Y. Fan (University of Arizona-Tucson), G. Gloeckler (University of Maryland), and L. J. Lanzerotti (Bell Telephone Laboratories, Murray Hill, New Jersey).

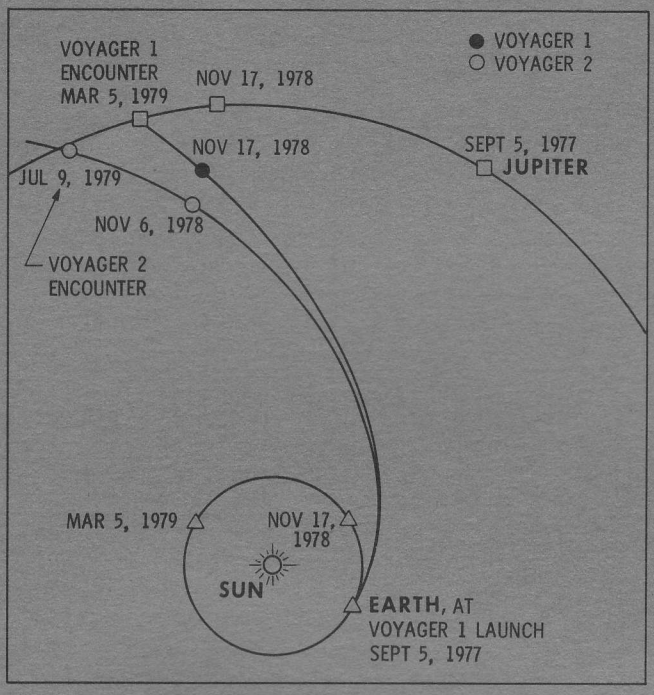
*39,897 kilometers (24,791 miles) per hour, set by American astronauts Stafford, Cernan, and Young in Apollo X on May 26, 1969, at an altitude slightly less than 122 kilometers or 76 miles.



MISSION STATUS BULLETIN

VOYAGER

November 17, 1978 **No. 26**



CLOSING IN. Voyager 1 has traced an arc of about 840 million kilometers (520 million miles) in its chase of the giant planet. Earth has completed 1-1/4 orbits of the Sun in that time, while Jupiter has traveled about 1/10 of its own orbit. One-way light time to Voyager 1 is 35 minutes 46 seconds. Voyager 2's arc distance is about 850 million kilometers (530 million miles), and one-way light time is 33 minutes 40 seconds. Soon, Voyager's Jupiter pictures will surpass the quality of Earth-based observations.

The Voyager Spacecraft

(This is the eighth in a planned series of brief explanatory notes on the spacecraft and its subsystems.)

Part 8 — Plasma Wave Investigation

As the twin Voyagers hurtled out of the earth's atmosphere, they soon entered a new environment where they are surrounded by a low-density, ionized gas called a "plasma." This plasma, composed entirely of atoms that are broken apart into electrons and charged positive ions, is a good electrical conductor with properties that are strongly affected by magnetic fields.

Plasma sources include the Sun, as well as the planets themselves and perhaps some of the satellites. Low density plasmas are unusual in other ways: ordinary collisions

(contd)

Update

Voyager 1 — IRIS Performance Improves

The infrared interferometer spectrometer (IRIS) performance has improved considerably as the result of a 54-hour warm-up initiated on October 24. The data indicates that proper operation has been restored in the Michelson motor which is used by both the reference and infrared interferometers. Symptoms of increased resistance to movement in the linear-travel motor had been present since July 1978. It was theorized that hardening of the motor dampers could be responsible for the problem.

Using the flash-off heater, the instrument optics module temperature was raised from 200° Kelvin (the normal operating point) to 275° Kelvin in an effort to reverse any crystallization and associated hardening of the motor dampers. The flash-off heater was installed to evaporate condensation accumulated in the launch phase. Future warm-ups of the Voyager 1 IRIS may be performed to maintain the improved performance.

Voyager 2 — Multiple Data Rate Tests

The last of three in-flight capability demonstration tests, the multiple data rate test, was run on November 14. During the 12-hour test, a 2-hour sequence exercising various data modes and rates was repeated six times. The data rates ranged from 7200 bits (of computer data) per second (bps) to 115,200 bps, while the modes ranged from general science to tape recorder playback and imaging.

During the encounter period, the spacecraft will be changing rates and modes frequently to gather as much information as possible. The purpose of the test was to familiarize ground personnel with the nature of the changing spacecraft signal data rates during the encounter sequence, to verify the capability of the ground data system to "lock" onto the signal and process it within the specified time, and to validate the mission planning allowance for data losses due to data rate changes.

PRA Communications Test

Another test of the communications link between Voyager 2's planetary radio astronomy (PRA) experiment's radio receiver and the radio telescope at Stanford University will be conducted on November 18. The six-hour test will further explore the adequacy of the signal strength against background interference. A possibility of communicating with Voyager through the PRA receiver, should the remaining radio receiver fail, exists, but would require new ground facilities and extensive re-programming of existing spacecraft software.

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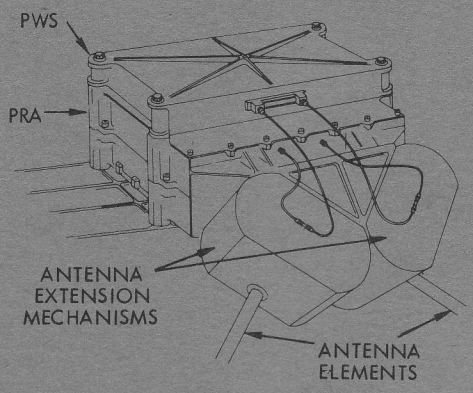


between ions are unimportant, and individual ions and electrons interact with the rest of the plasma by means of emission and absorption of waves. These localized interactions between waves and particles strongly control the dynamics of the entire plasma medium, and the Voyager plasma wave investigation (PWS) will provide the first measurements of these phenomena at the outer planets.

What are Plasma Waves?

The plasma waves are low-frequency oscillations that have their origins in instabilities within the plasma, and they are of two types, either electrostatic oscillations (similar to sound waves) or electromagnetic waves of very low frequency. The PWS measures the electric field component over the range of frequencies between 10 and 56,000 Hertz (Hz). In comparison, Voyager's magnetometer measures the magnetic vectors of electromagnetic plasma waves below 10 Hz, while the planetary radio astronomy instrument measures waves with frequencies over 56 kHz.

The plasma ions and electrons both emit and absorb plasma waves. While the resulting particle-wave interactions are known to affect the magnetospheric dynamics of the outer planets and the properties of the distant interplanetary medium, they have never been directly observed in these regions, since plasma waves cannot generally be observed far from the source and since there have been no previous wave investigations at the outer planets.

Voyager will return the first direct observations of wave-particle interactions at this distance from the Sun. Some of the effects to be studied include the heating of solar wind particles at the outer planet bow shocks (the line of interaction between the solar wind and the planetary magnetospheres), the acceleration of solar wind particles that produce high-energy trapped radiation, and the maintenance of boundaries between the rotating inner magnetospheres and the solar wind streaming around the planets.

Another objective is to study the influence of wave-particle effects on the interactions between the inner satellites of the major planets and the planets' rapidly rotating magnetospheres. Control of Jupiter's decametric (10 kilometer) radio bursts through the coupling of the satellite Io's ionosphere with the planet's magnetic field is an example, and special intensive plasma wave measurements will be made as Voyager 1 passes through the Io "flux tube", where strong current systems are driven by Io's motion through the Jovian magnetosphere. An analogy is the current produced by a conductor moving through a magnetic field. Io is thought to have salt deposits on its surface which are weakly conducting. As Io moves through Jupiter's magnetic field, it produces current flow along the magnetic field lines connecting Io to Jupiter (the 'flux tube').

Detection of lightning discharges in the atmospheres of Jupiter and Saturn would also be very significant. The plasma wave investigations will search for the audible "whistler" signals that escape into the magnetosphere from such discharges. The characteristic descending whistle that is detected from lightning is due to the scattering of similar velocities when the direction of travel is along magnetic lines of force: the higher frequencies of a broadband pulse arrive at the receiver in advance of lower frequencies. Using high-rate telemetry usually used by the imaging subsystem, the PWS will be able to send back the entire audio signal in the range 50 Hertz (Hz) to about 14.4 kHz.

The instrument will actually return "sounds" of low-frequency waves in the plasma surrounding the spacecraft. Some of these waves may be caused by the spacecraft's power system, the firing thrusters, or other instruments aboard the craft.

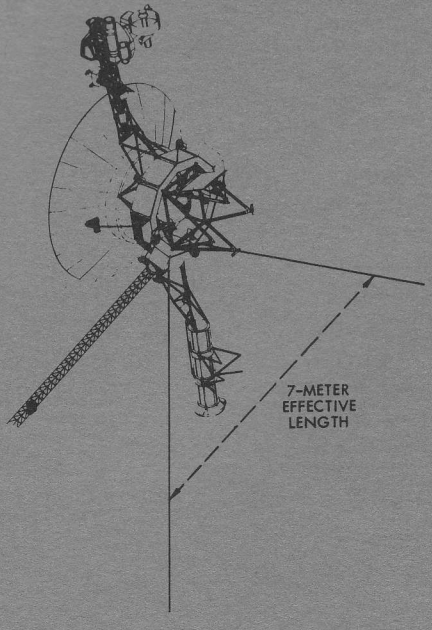
Instrumentation and Investigators

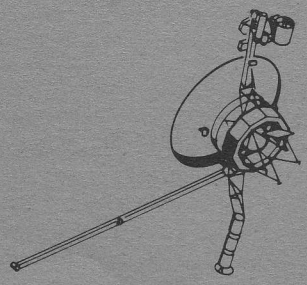
A late addition to the Voyager complement of fields and particles experiments, the PWS joined the mission in mid-1974 after the spacecraft design and mission plan were well along. The PWS shares the planetary radio astronomy experiment's two 10-meter (33-foot) antennas, but uses them entirely differently, as a balanced electric dipole rather than as a pair of orthogonal monopoles, as shown in the figure.

The beryllium-copper antennas, about one-half inch in diameter, were rolled flat onto a spool, and then extended by command after launch. Astro Research Corporation, Santa Barbara, California, designed and fabricated the antennas.

Plasma wave signals are processed with a 16-channel spectrum analyzer, which provides a frequency sampling from 10 Hz to 56 kiloHertz (kHz) every four seconds during planetary encounters. In addition, the broadband audio amplifier, in combination with the Voyager video telemetry link, gives electric field waveforms over the frequency range 50 Hz to 14.4 kHz at selected times during the encounter periods. The electronics, which ride piggyback atop the PRA electronics box, were designed and built by the physics department of the University of Iowa.

Principal investigator for the PWS is F. L. Scarf, TRW Defense and Space Systems Group, Redondo Beach, California. Co-investigator is D. A. Gurnett of the University of Iowa, while W. Kurth of the University of Iowa is in charge of data processing.





MISSION STATUS BULLETIN

VOYAGER

December 6, 1978 **No. 27**

Mission Highlights

A flurry of activity in early December will conclude the flight team's test and training period, and will be followed by a 2-week period of low activity on-board the spacecraft to give flight team members a break before Encounter Operations begin in earnest with the Observatory phase on January 4, 1979.

Most of the activity will center around the encountering spacecraft, Voyager 1, while the cruising spacecraft, Voyager 2, will continue its routine calibrations and housekeeping chores.

Near Encounter Test

Highlight of the spacecraft activities in Voyager 1's final month of the Earth-to-Jupiter cruise phase will be the Near Encounter Test on December 12 through 14. This will be a thorough preview of the 39-hour period on March 3 through 5, 1979, when Voyager 1 will make its closest approach to the giant planet Jupiter.

The Near Encounter Test will put the spacecraft, tracking stations, and flight team through their paces in a scenario as near the real thing as possible. Instrument pointing will be restricted during the test, however, as many of the instruments must not point within 20 degrees of the Sun. During closest approach in March, the Sun will be blocked from the instruments' views by the planet and satellites, but during the December test precautions will be taken to protect the instruments.

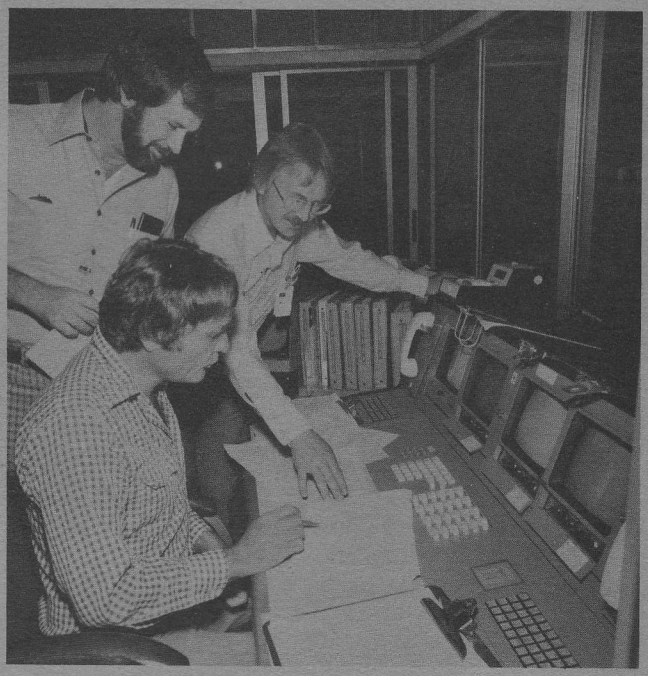
Assessment of the Near Encounter Test performance should be completed by January 5.

Test and Training

The Voyager Project acquired a new spacecraft in November, but this one is a phantom and all of its activities are simulated, since it is used for test and training. No data from this spacecraft ever appears on a controller's display, but detailed timelines of its activity are always within reach, and its data conditions are passed by voice or slips of paper.

Why the elaborate "game"? The problems of the phantom spacecraft stimulate utilization of recovery procedures and the tactics of applying resources to problem solving. Anomalies of all sorts are simulated: antennas begin to drift off point, high winds suddenly force the stowing of simulated stations imperiling critical data playback, key personnel become mysteriously incapacitated. All of this could happen for real, at any time of day or night, and so the flight team is geared to cope with any contingency. Nothing must go wrong during the critical encounter period in March.

The three key encounter sequences to be transmitted to and executed by Voyager 1 in early March have been tested under real pressures and real schedules, while the two cruising spacecraft have provided practice in real data analysis. And although a fine line is followed between impacting on-going operations and the requirement to train for Encounter, one never knows when the emergency could be real. . .



AFTER A PHANTOM — Keeping track of simulated spacecraft events during test and training are (seated) Wayne Henry, lead mission controller, and (standing, from left) Gerry Stillwell, deputy mission control team chief, and Rod Zieger, mission control team chief.

NASA
National Aeronautics and Space Administration

Recorded Mission Status (213) 354-7237
Recorded Mission Operations Status (213) 354-6665
Status Bulletin Editor (213) 354-4438

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Readiness Reviews

Prior to the Near Encounter Test, a series of readiness reviews will be conducted to assess preparations for Jupiter Encounter.

On December 5, the ground data system (GDS) will be reviewed, with reports on the tracking stations, computing facilities, data lines, and procedures. Also on December 5, the imaging review will assess the status of the imaging system and the plans for imaging during the Encounter phases.

The Encounter Operations Readiness Review will be held on December 7, with reports on the readiness of the flight team, the Deep Space Network, the mission control and computing center, and the public affairs office.

Finally, on December 11, the final cruise-phase meeting of the Science Steering Group will brief the scientists on Voyager 1's Jupiter Encounter preparations status and the science investigators will report on the status of their respective instruments aboard the craft.

Imaging

Voyager 1 is expected to return Jupiter images this month which will exceed the resolution of all previous Earth-based photographs of the giant planet. Beginning December 10, a 20-hour "movie" of the planet will be taken, with shuttering of the cameras every hour. This period will cover two rotations of the planet, and will provide 3-color coverage of the planet every 36 degrees of Jovian rotation. The movie to be taken in late January will involve shuttering the cameras every 96 seconds and will provide 3-color coverage of the planet every 3 degrees of the planet's rotation.

	Distance from Earth	Distance to Jupiter	One-Way Light Time	Heliocentric Velocity
VOYAGER 1:	618 million km (384 million mi)	90 million km (56 million mi)	34 min 24 sec	50,706 kph (31,500 mph)
VOYAGER 2:	574 million km (357 million mi)	154 million km (96 million mi)	31 min 49 sec	46,090 kph (28,639 mph)

The Voyager Spacecraft

(This is the ninth in a planned series of brief explanatory notes on the spacecraft and its subsystems.)

Part 9 — Radio Science

The same radio system that provides tracking and communications with Voyager will be used to explore the planetary systems and interplanetary space.

Measurements of Voyager's radio communication waves will provide information on the gravitational fields and atmospheres of the planets and their satellites, the rings of Saturn, the solar corona, and general relativity.

Science Objectives

Changes in the frequency, phase, delay, intensity, and polarization of the radio signals between Earth and the spacecraft provide a wealth of information about the space between the two and about the forces that affect the craft and alter its path.

For example, the gravity fields of the planets and satellites will pull on the spacecraft, altering its velocity and thus changing the radio frequency. The mass density of the satellites and the internal structures of the planets can then be calculated from the observed effects on the spacecraft.

When the spacecraft moves behind a celestial body, as viewed from Earth (called occultation), the radio waves coming from the spacecraft will pass through the atmosphere and ionosphere of that body on their way toward Earth. Changes in the signal characteristics during these periods will give information about the vertical structure of the atmosphere, ionosphere, clouds, turbulence, and possibly, weather.

As Voyager 1's microwave signals pass through the rings of Saturn in 1980, the nature of the rings will be investigated. Rock particles would affect the signal differently than would water or ammonia ices. Various sizes of particles will also be evident and scattering of the radio waves will provide a measure of the total amount of material (and of what sizes) in the rings.

Occultation measurements will be made at Jupiter, Saturn and its rings, the Saturnian satellite Titan, and possibly Uranus (by Voyager 2 in 1986).

Voyager 1's radio waves will pass by Jupiter's equatorial region, while Voyager 2's rays will pass near the south polar region. As the radio signals pass through the planet's atmosphere, profiles of the relative temperature and pressure of the gases at various distances from the surface will be compiled. This and other data can be used to determine the amounts of the various elements in the atmosphere as compared to each other (the abundance ratios).

Except for the first months of their journeys, the two spacecraft appear close together in the sky as seen from Earth by the Deep Space Network's antennas. When the Earth moves to the opposite side of the Sun from the spacecraft (superior conjunction), as will happen several times during the mission, it will be possible to see changes in the radio signals as they pass near the solar corona regions on their way to Earth. In the fall of 1979, a unique alignment of Earth, the Sun, and the Voyager, Pioneer, and Helios spacecraft will allow an intensive study of the Sun's properties because the ray paths from each spacecraft will probe a different region of the solar corona, making possible nearly simultaneous measurements.

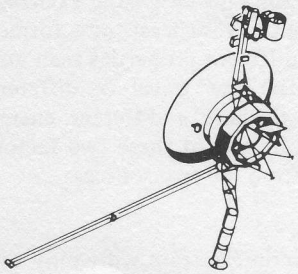
Instrumentation

Voyager's radio equipment includes several improvements over previous planetary missions, both for engineering and scientific purposes. These include coherent, high-power 3.5- and 13-centimeter wavelength amplifiers, increased antenna size [the 3.66-meter (12-foot) diameter antenna dish is the largest of its type ever flown], an ultra-stable oscillator, improved phase and group delay stabilities in the spacecraft transponder, and an attitude control thruster design which reduces spacecraft accelerations along the Earth-spacecraft line-of-sight.

The radio science instrumentation uses a new onboard stabilized frequency reference, known as the ultra-stable oscillator (USO). Compared to previous spacecraft radio systems, the USO makes Voyager less sensitive to thermal and electrical changes, as well as to radiation effects. The USO is designed to give maximum frequency stability for periods from 1 second to 10 minutes.

Investigators

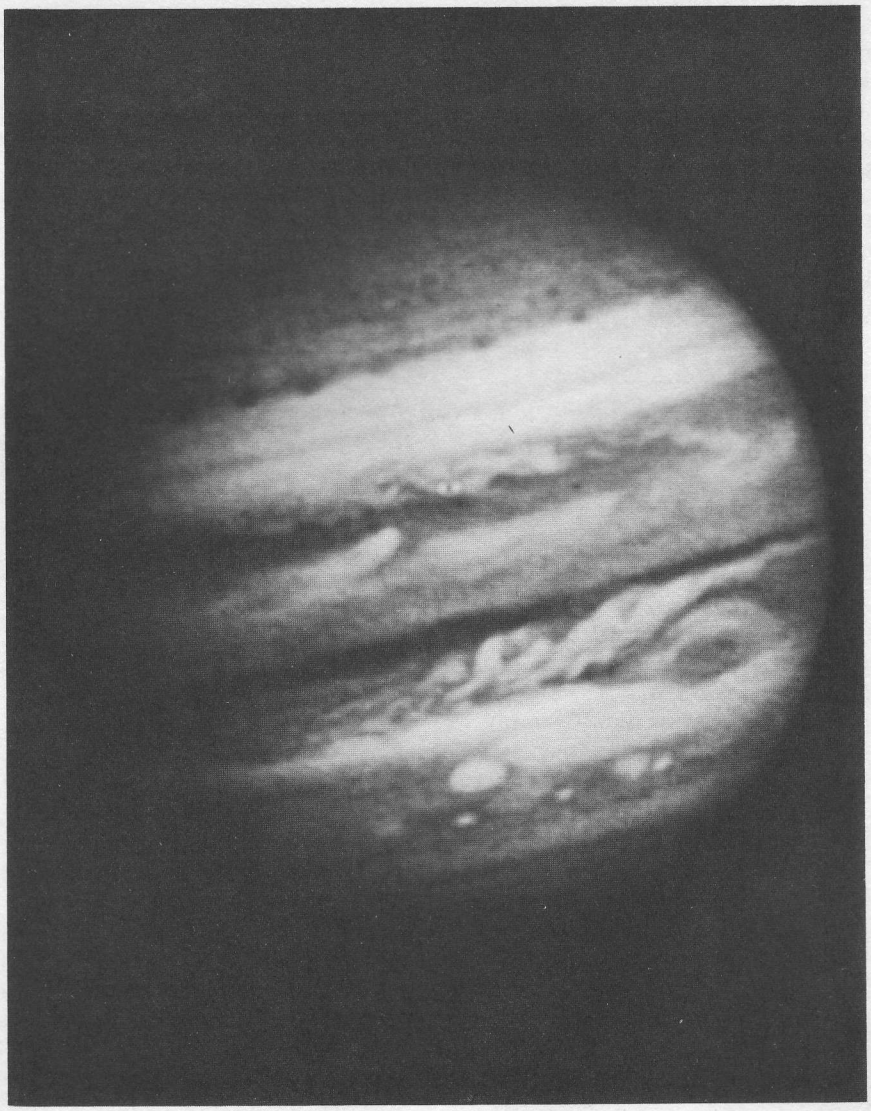
V.R. Eshleman of Stanford University (California) is the radio science team leader. Team members include G.L. Tyler (Stanford), T.A. Croft (Stanford Research Institute, Menlo Park, California), and J.D. Anderson, G.F. Lindal, G.S. Levy, and G.E. Wood (JPL).



MISSION STATUS BULLETIN

VOYAGER

December 15, 1978 **No. 28**



DYNAMIC JUPITER – Revealing more detail than the very best groundbased telescopic photographs, this Voyager 1 image of Jupiter, taken December 10 from 83 million kilometers (52 million miles) shows the Great Red Spot (lower right) surrounded by a colorful and turbulent atmosphere. The entire visible surface of Jupiter is made up of multiple layers of clouds, composed primarily of ammonia ice crystals colored by small amounts of materials of unknown composition. Near the center is a bright convective cloud and an associated plume which has been swept westward (to the left) by local currents in the planet's equatorial wind system. This same atmospheric feature was seen prominently in the Pioneer 10 and 11 spacecraft pictures of Jupiter taken four and five years ago this month. Below and to the left of the Great Red Spot is a white oval cloud, one of three which formed nearly 40 years ago in the south temperate region. This picture was taken with a slow-scan TV camera equipped with a 1500 millimeter focal-length telescope. The color image was recreated from three TV frames, each taken through a different filter – green, orange and blue.

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The Voyager Spacecraft

(This is the tenth in a planned series of brief explanatory notes on the spacecraft and its subsystems.)

Part 10 – Plasma Investigation

Deep space has long been characterized as a cold, dark void. In truth, it is none of these. It is filled with planets, stars, dust, and clouds of low density, high-speed, ionized gases called plasma, which originates from both the Sun and other stars.

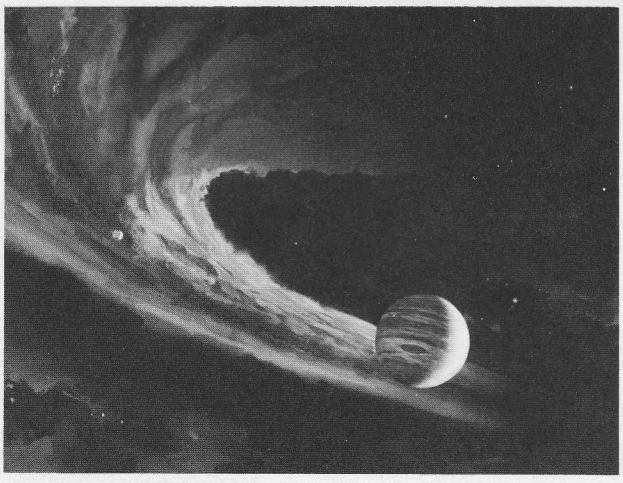
Travelling at supersonic speeds (averaging 400 kilometers or 250 miles per second), plasma streams from the Sun in all directions, forming the solar wind. When the solar wind interacts with the earth's magnetic field, many interesting phenomena result, such as the northern lights and large geomagnetic storms. Similar effects have been observed at other planets.

Voyager's plasma experiment, one of the array of fields and particles investigations, will measure plasma properties including velocity, density, and temperature for a wide range of flow directions in both the solar wind and magnetospheres.

Interstellar Ions, Solar Winds and Donuts

As are all of Voyager's fields and particles instruments, the plasma experiment (PLS) is designed to explore a range of environments – interplanetary space, planetary systems, and interstellar space.

During interplanetary cruise, the principal scientific objective is to study the properties and radial evolution of the solar plasma. A complete description of plasma properties in this region requires detailed information not only about the speeds and directions of plasma ions and electrons but also about the direction and strength of the magnetic field. For this reason, PLS data reduction is being carried on as a joint effort by the plasma and magnetometer investigators. Analysis of cruise data is now proceeding routinely; data from Voyager 1 has been processed from launch to about 4.5 AU and data from Voyager 2 to about 4.2 AU.



A wide, donut-shaped ring of hydrogen partially encircles Jupiter, while thinner rings of hydrogen and sodium trail the path of Io in this artist's conception.

A secondary cruise objective is to search for ions formed from the neutral interstellar gas. This gas is ionized by ultraviolet light from the Sun and by charge exchange with ions of the solar wind. Initially, at least, ions formed from the interstellar gas have different properties than ions of the solar wind: interstellar ions travel in different directions and are expected to have a different energy distribution. It is hoped that tracking of these two factors will allow a separation of ions from the two sources.

At Jupiter, the PLS experiment team will study the interaction of the solar wind with Jupiter; the sources, properties, form, and structure of the Jovian magnetospheric plasma; and the interaction of the magnetospheric plasma with Jupiter's Galilean satellites.

The second satellite from the planet, Io, is known to be a source of neutral hydrogen, potassium, and sodium atoms which form an incomplete donut-shaped ring (torus) close to the orbit of Io. In addition, there is an ionized cloud of sulfur associated with Io which has been observed by ground-based telescopes. Although the PLS cannot observe the neutral atoms in these clouds directly, the neutral gas is eventually ionized and becomes part of the Jovian magnetospheric plasma. The PLS has been designed to detect ionized sodium and sulfur close to the orbit of Io.

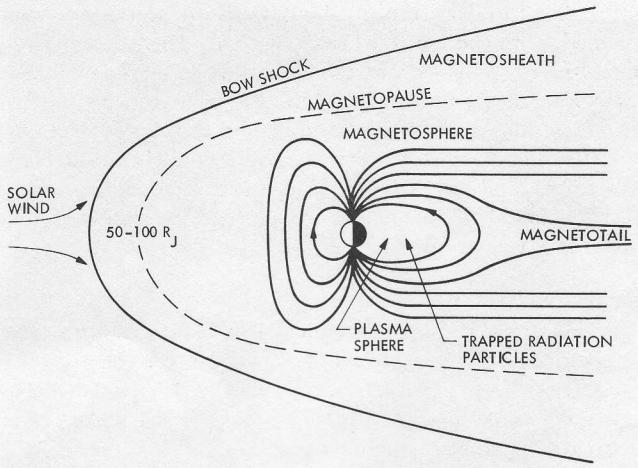
It is possible that Ganymede, the fourth satellite from the planet, may also have a ring of neutral particles which serve as a source for ions in the Jovian magnetosphere. If that is the case, the PLS should detect some of these ions when the spacecraft is close to the orbit of Ganymede (closest Ganymede approach will be from about 120,000 kilometers).

At Saturn, particular attention will be given to the interaction of plasma with the planet and its satellites, especially Titan. It is not yet clear if Titan's orbit is within Saturn's magnetosphere plasma envelope, or outside leaving its "wake" in the solar wind plasma instead. Voyager 1's flight path will allow exploration of either case.

Solar Wind – Magnetosphere Interactions

Jupiter's magnetosphere is enormous, extending into space a distance of about 100 times the planetary radius (100 R_J). As Jupiter's radius is about 71,400 kilometers (44,000 miles), this places the outer edge at about 7 million kilometers from the center of the planet. These distances are typical for a "quiet" magnetosphere. On two occasions, however, the magnetopause has been found at 50 R_J, and it is likely that this compression is caused by an increase in the pressure of the solar wind. During the encounter of Voyager 1 with Jupiter, the pressure of the solar wind at Jupiter and the size of the Jovian magnetosphere can be predicted from data returned by Voyager 2. In this way, comparison of PLS data from both spacecraft during the first Jupiter encounter will show unambiguously how the Jovian magnetosphere responds to changes in the incoming solar wind.

Voyager's first contact with Jupiter's magnetosphere will be signalled by the crossing of the bow shock, the line of demarkation between the undisturbed solar wind and the Jovian environment. Voyager 1 is expected to cross the bow shock about February 26, 1979, nearly a week before closest approach.



Jupiter's magnetosphere is expected to be similar to Earth's

Immediately behind the bow shock is a transition region called the magnetosheath which separates the solar wind and the magnetosphere. The inner boundary of the magnetosheath, the magnetopause, is the surface which separates the modified solar wind plasma in the Jovian magnetosheath from the plasma of the Jovian magnetosphere proper. Coming directly from the solar wind, the magnetosheath plasma is slowed down and heated by passage through the bow shock. Plasma in the magnetosphere, however, comes from several sources: the ionosphere of Jupiter, ions from satellite surfaces and atmospheres, and the solar wind.

Planetary magnetic field lines physically connect the upper atmosphere of the planet with the solar wind. The Jovian ionosphere is thought to be a source of plasma which travels along these field lines, sometimes being trapped by the planetary magnetic field and sometimes managing to escape directly into the solar wind.

Other probable sources of magnetospheric plasma are the neutral hydrogen, sodium, and potassium atoms, and the ionized sulfur observed near Io; ions from the solar wind, and finally ions from the interstellar gas.

In the inner magnetosphere, plasma trapped by the magnetic field is forced to rotate with the planet. This region of corotation may extend as far as the magnetopause, and the further from the planet, the more the centrifugal forces cause stretching of the magnetic field lines, more or less parallel to Jupiter's equator.

The stretched field lines give rise to a thin disk in which the trapped particles are confined, forming an intense, thin sheet of current flowing around the planet.

At Earth, the solar wind streams around the planet and forms a drawn-out magnetotail on the far side of the planet. A similar tail probably exists at Jupiter as well, and Voyager will make preliminary measurements in this region.

The plasma within the magnetosphere is far from quiet: the solar wind introduces disturbances such as solar flare events; satellites moving within the magnetosphere leave "wakes" similar to ships in the ocean; instabilities build. Global instabilities of the plasma, called magnetospheric substorms, cause auroral displays at Earth as the upper atmosphere interacts with the substorm. Because of the size of Jupiter's magnetosphere, the typical time scale for the development of plasma instabilities should be on the order of days, not hours, as at Earth, thus allowing more detailed study by the Voyagers as they traverse the area.

Instrumentation

The PLS uses two detector systems; one points at Earth while the other points at right angles to the Earth-spacecraft line.

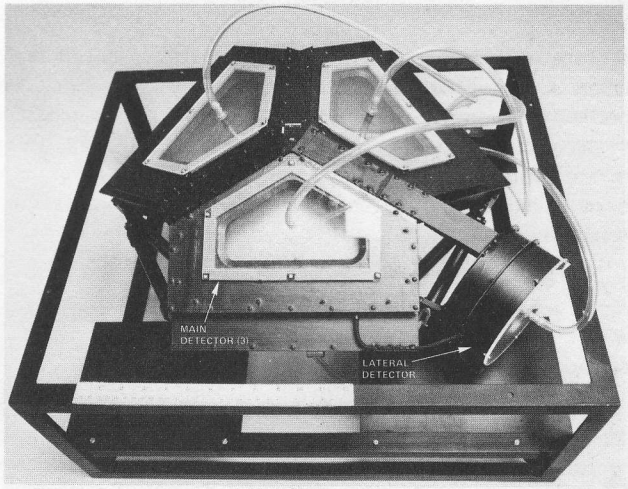
Both detector systems use Faraday cups, named after the 19th-century English physicist and chemist who studied the relationships between visible light and the electromagnetic spectrum. A conventional Faraday cup consists of a collector, several grids, and one or more apertures which define the field-of-view.

The Earth-pointed detector measures positive ions in the range from 10 to 5950 volts, and covers a broad range of possible plasma speeds from subsonic to supersonic flows. Simultaneous measurement of solar wind properties and search for interstellar ions is possible.

The Earth-pointed detector uses three Faraday cups which form three faces of a shallow tetrahedron. In this configuration, each cup views a common region of space in a different direction. This feature of the detector is new, allowing for the first time a full three-dimensional analysis of the velocity distribution function of the plasma ions. In addition, each cup views a different section of space, giving full-sky coverage when combined with spacecraft turns. This detector measures the solar wind plasma during cruise and the Jovian plasma when Voyager encounters the giant planet.

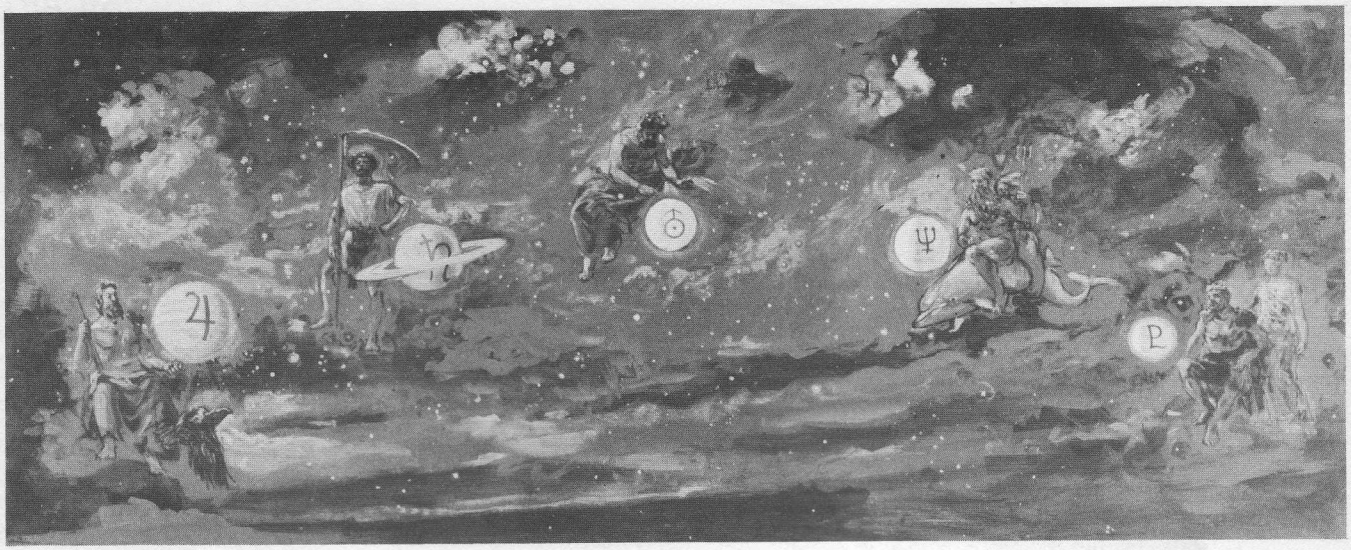
The second detector uses one conventional Faraday cup pointed perpendicularly to the Earth-pointed system and views 1/12 of the full sky. It measures both positive ions and electrons from 10 to 5950 electron volts. As the spacecraft turns, this detector will scan the sky from pole to pole.

Mounted on the science boom, the instrument weighs about 9.9 kilograms (21 pounds) and draws about 8 watts of power.



Investigating Team

H. S. Bridge of the Massachusetts Institute of Technology is the plasma experiment principal investigator. Co-investigators are J. W. Belcher, A. J. Lazarus, S. Olbert, and J. D. Sullivan (MIT); L. F. Burlaga, R. E. Hartle, and K. W. Ogilvie (Goddard Space Flight Center); A. J. Hundhausen (High Altitude Observatory, Unviersity of Colorado); C. M. Yeates (JPL); V. M. Vasyliunas (Max-Planck-Institut für Aeronomie, Katlenburg-Lindau, West Germany); and G. L. Siscoe (University of California at Los Angeles). The instrument was built at MIT by an engineering team headed by R. Butler.



OUTER PLANETS – The ancient gods await man as classical mythology and planetology mix in this rendering executed for the National Air and Space Museum. Jupiter, largest planet in our solar system, is named in honor of the chief god, known as Zeus to the Greeks. A sky god, his weapons are thunder and lightning. The father of Jupiter is Saturn (Cronus), leader of the elder gods, the Titans. Uranus ("Heaven") was an early Greek god, while Neptune (Poseidon), god of the sea, is a stormy brother of Jupiter. Finally, another Jovian brother, Pluto, ruled the underworld and the afterlife.

Update

Voyager 1

In these last weeks of Voyager 1's cruise phase, mission operations have been a whirlwind of activity, interleaving crucial calibrations and tests with reviews assessing project readiness.

On December 10–11, a 20-hour sequence of two rotations of the giant planet returned exciting images which will be used in selecting interesting features to be further explored during Encounter.

A target maneuver was cancelled on December 5 when a timing offset between the two processors of the on-board computer command subsystem was noticed. The 48-second difference between the two would have resulted in an aborted maneuver. Periodic target maneuvers have been executed on both spacecraft and the possibilities of rescheduling this maneuver are being explored.

One of four apertures in the photopolarimeter instrument was tested on December 6. The instrument's aperture wheel was turned to the 0.25 degree diameter aperture to test its field-of-view.

Just prior to the Near Encounter Test (December 12–14), the sun sensors/high gain antenna, scan platform pointing, and imaging optics were calibrated on December 11.

A review of the test and training activities, including the Near Encounter Test, essentially a dry-run of the activity planned and programmed for the 39 hours around closest approach to Jupiter on March 5, is scheduled for December 15.

Two weeks of relative quiet will follow, and then Voyager 1's Observatory phase will begin on January 4, 1979.

Voyager 2

The second spacecraft has been enjoying a quiet month with little activity other than periodic instrument calibrations.

Voyager in the Smithsonian

A museum piece at a tender age, Voyager holds a prominent position in the new "Exploring the Planets" gallery at the Smithsonian Institution's National Air and Space Museum, Washington, D.C.

The exhibit, which opened this fall, takes visitors on a tour of the solar system and imparts some of the knowledge scientists have acquired in exploring the planets via space missions and observations from Earth.

The largest single object in the gallery is a full-scale replica of a Voyager spacecraft, suspended from the ceiling and with all booms and antennas fully extended, including the 43-foot magnetometer boom!

Below the spacecraft, a television screen currently shows an animated film about the project, and will carry the latest information from the planet as Voyager closes in.

Other special exhibits in the gallery include a flight over Mars, a descent to Venus, relative sizes of planetary bodies (from a 10-foot diameter Jupiter to a 1-foot diameter Earth to a 1-inch diameter Ceres, the largest asteroid), computer terminal games, comparative planetology, planetary weather reports, and "Unanswered Questions" – some of which Voyager hopes to answer.

Summary

Eighty days and 78 million kilometers (49 million miles) lie between Voyager 1 and its first objective, Jupiter. While it is currently travelling at a heliocentric velocity of 14 kilometers per second, one-way communication time with the ship is 33 minutes 51 seconds, 609 million kilometers (378 million miles) from Earth.

Voyager 2 has 146 million kilometers (91 million miles) to travel in the next seven months before meeting the giant planet. One-way light time is 31 minutes 10 seconds, while its heliocentric velocity is 12.6 kilometers per second.

Voyager Bulletin

MISSION STATUS REPORT NO. 29 JANUARY 4, 1979

Mission Highlights

Voyager 1 Jupiter Observatory Phase Begins

Sixty days and sixty million kilometers from Jupiter, Voyager 1 begins its Jupiter observatory phase on January 4. The events of the next twenty-six days are designed to provide a time history of scientifically important phenomena on Jupiter.

Most of the observations in this phase are repetitive, to provide a data base for all ensuing data. Significant calibration sequences occur between January 4 and 6 to prepare for the Jovian encounter.

On January 6, the imaging cameras will begin to record a series of four, single narrow-angle images, each in a different color. Taken every two hours (every 72 degrees of Jupiter rotation), the series is part of a long duration study of large-scale atmospheric processes. These images will be examined to determine the most dynamic features on Jupiter and to allow retargeting to them during the near encounter period.

Daily "system scans" by the other optical instruments will provide a large-scale look at the entire Jovian system. The ultraviolet spectrometer (UVS) will raster the system eight times each day for two hours, looking for the distribution of ultraviolet emissions. The infrared interferometer spectrometer (IRIS) will collect about 100 infrared spectra of Jupiter in a 1½-hour period once a day, sampling different longitudes.

The photopolarimeter (PPS) scans will search for the edge of Io's sodium cloud, expected to extend as far as 60 Jupiter radii (R_J) (4.3 million kilometers or 2.7 million miles) from Jupiter, nearly 10 times farther than Io's orbital radius.

In addition, the system scans include a search for the bow shock, the intersection of the solar wind plasma and the planetary magnetosphere.

The planetary radio astronomy/plasma wave duo will search for Jupiter radio bursts and perturbations of the plasma once a day. All of the fields and particles instruments will begin an accelerated level of daily measurements to characterize the beginning of Jupiter's influence in the sea of solar wind particles that dominates most of the space in the solar system.

The daily accumulations of data will fill nearly eight tracks a day on the on-board digital tape recorder that consists of one 8-track magnetic tape about 328 meters (1076 feet) long. The tape will be played back to Earth daily, taking approximately three hours each time.

Only the 64-meter (210-foot) antennas of the Deep Space Network have the capability to receive the daily playbacks. Seven and one-half hours of daily coverage will be provided by the 64-meter antenna at Madrid, Spain, since this station will be in view of the spacecraft during prime shift working hours (at JPL) throughout the observatory phase. The DSN's 26- and 34-meter antennas will monitor the ship during the remaining 16.5 hours each day.

Astronomy Notes

On January 4, Earth reaches perihelion, its closest approach to the Sun during the year. On this day, Earth will be 147 million kilometers (91 million miles) from the Sun.

Jupiter reaches opposition on January 24, when it will be directly opposite the Sun from the Earth. Throughout January, Jupiter will be exceptionally bright and visible all night. Currently in the constellation Cancer, Jupiter will be north and east of the bright star Sirius this month.

The Voyager Spacecraft

(This is the eleventh in a planned series of brief explanatory notes on the spacecraft and its subsystems.)

Part 11 — Photopolarimeter Experiment (PPS)

By studying sunlight scattered by the atmospheres and surfaces of the planets and satellites, Voyager's photopolarimeter experiment will unveil many secrets of the outer planets.

Eight wavelengths in the ultraviolet and visible regions of the spectrum (from 2350 to 7500 Angstroms) will be measured in intensity (brightness) to determine the physical properties of the atmospheres of Jupiter and Saturn (perhaps seeing evidence of lightning and auroral activity), the rings of Saturn, the satellite surfaces, and the sodium cloud around Io.

Scientific Objectives

The photopolarimeter will examine both the large- and micro-scale structure and properties of the clouds of Jupiter, Saturn, and the Saturnian satellite Titan. It will

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probe the vertical distribution of cloud particles, as well as the particle size and shape, and provide inferences on atmospheric composition.

Similar studies will define the structures of major planetary features such as Jupiter's Great Red Spot, zones, and belts. The photopolarimeter will search for evidence of crystalline particles in these features, and will gather data on the effects of scattering and absorption of sunlight by these particles, and the resulting effect on thermal balance. From these data, additional model calculations will be made, providing insight into domains impenetrable by Voyager's complement of remote sensing instruments.

The atmospheres will be compared to two already well-known samples – the thick, hazy, warm atmosphere of Venus, and the more familiar atmosphere of Earth.

At the satellites of the outer planets, the photopolarimeter will probe the density of the atmospheres (where they exist), the texture and possible compositional variations (on a large scale) of the surfaces, the bulk reflectivity, and the sodium vapor cloud around Jupiter's Io.

The spectral reflectivity of a body can aid in determining its surface composition, be it bare rock, dust, frost deposits, ice, or meteor remains.

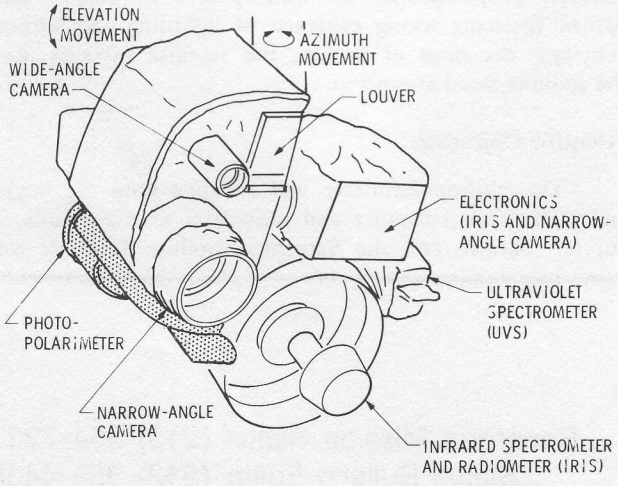
Io's Encircling Cloud

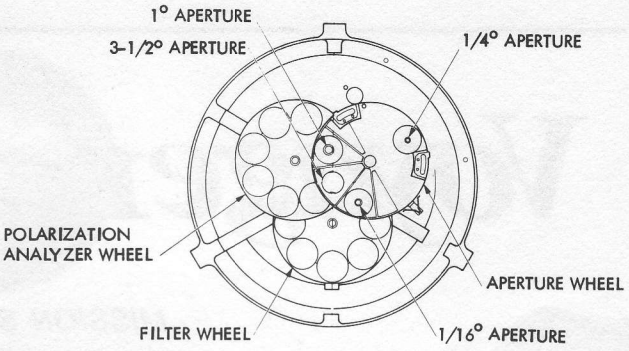
The first suggestion that gases escaping from the satellite atmospheres might be unable to escape from the planetary gravity fields and would thus form doughnut-shaped rings (toruses) around the planet, was made in 1973. Since then, it has been confirmed that such a toroid does indeed exist in the vicinity of Jupiter's satellite Io, and that it is composed primarily of sodium and atomic hydrogen. It extends from about three times the radius of Jupiter ($3\ R_J$) to beyond 10 times the radius ($10\ R_J$). Io, and perhaps Amalthea and Europa, orbit within this cloud, and Voyager will search for it during the far encounter phase as it sails closer to the giant planet.

Io seems to be covered by evaporite salts, including atomic hydrogen, sodium, potassium, and sulfur, and possibly atomic magnesium, calcium, and silicon. These are sputtered off from Io's salt-covered surface into its atmosphere by charged atomic particles (ions) which are trapped in Jupiter's strong magnetic field.

Ring Puzzles

Finally, the photopolarimeter will probe the rings of Saturn, including the size and shape, and allow inferences on the probable composition of the ring particles, their density, and radial distribution. The dynamics of the rings





will also be probed: Why are there several distinct rings, which do not appear to merge? Is there an atmosphere between the rings? What are the lifetimes of particles in the rings? How does the gravitational field of Saturn hold these rings in orbit?

Instrumentation

Mounted on the scan platform, Voyager's photopolarimeter is a combination photometer/polarimeter with filters. Light is gathered through a 6-inch-diameter Cassegrain telescope and passed through an aperture, a polarization analyzer, a filter, and a depolarizer before being converted into electrical pulses which indicate the number of photons (a measurable unit of light) in a particular energy band (color or wavelength), and polarization.

The apertures, analyzers, and filters are all mounted on separate wheels which turn independently of each other and so provide a great number of combinations. Normal operation during Encounter would consist of stepping through a programmed sequence of 40 filter/analyzer wheel combinations every 24 seconds.

There are four apertures providing 1/16, 1/4, 1, and 3-1/2-degree diameter circular fields of view. Eight positions on the analyzer wheel provide open, dark, a calibration source, and five Polacoat analyzers with their transmitting axes located at 0, 60, 120, 45, and 135 degrees rotation. Eight filters measure wavelengths from 2350 through 7500 Angstroms, each corresponding to the spectral features of specific elements or compounds (for example, sodium D, hydrogen, helium, calcium, magnesium, silicon, and potassium atoms, ozone, and hydroxyl radicals). Some filters measure scattering and methane absorption.

Instrument Status

Voyager 1's analyzer wheel has been sticking periodically throughout cruise, and efforts to regain completely normal operation have been stymied. Laboratory tests on the flight spare instrument indicate that a similar problem may occur with the filter wheel. During Jupiter Encounter, therefore, the analyzer wheel will be in the clear position only and the filter wheel will be allowed to step for only 50 hours during the near encounter period. The polarization data will be lost.

Investigators

Sharing the role of principal investigator are C. F. Lillie (cruise) and C. W. Hord (Encounter), both of the University of Colorado. Co-investigators are D. L. Coffeen and J. E. Hanson (Goddard Institute for Space Studies, New York), and K. Pang (Science Applications, Inc.).

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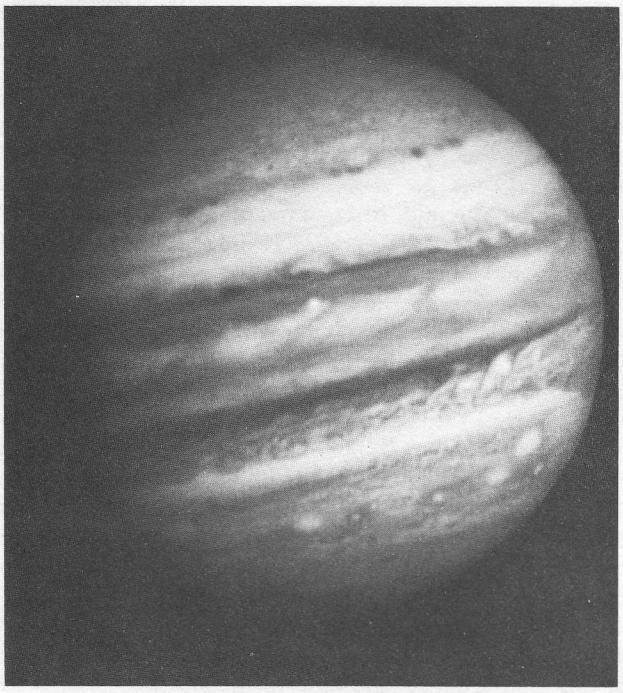

ENCOUNTER MINUS 58 DAYS – Voyager 1 took this picture of the planet Jupiter on January 6, the first in its three-month-long, close-up investigation of the largest planet. The spacecraft, flying toward a March 5 closest approach, was 57.6 million kilometers (35.8 million miles) from Jupiter and 598.2 million kilometers (371.7 million miles) from Earth. As the Voyager cameras begin their meteorological surveillance of Jupiter, they reveal a dynamic atmosphere with more convective structure than had previously been thought. While the smallest atmospheric features seen in this picture are still as large as 1,000 kilometers (600 miles) across, Voyager will be able to detect individual storm systems as small as 5 kilometers (3 miles) at closest approach. The Great Red Spot can be seen near the limb at the far right. Most of the other features are too small to be seen in terrestrial telescopes.

Summary

Voyager 1, 52.9 million kilometers (32.8 million miles) from Jupiter, has settled into its daily routine of imaging observations, system scans, infrared samplings, and playbacks. One-way light time is 33 minutes 18 seconds.

Voyager 2 is cruising quietly, with several routine calibrations scheduled for the next week. At 127.4 million kilometers (79.2 million miles) from Jupiter, one-way light time to Earth is 30 minutes 2 seconds.

The Voyager Spacecraft

(This is the twelfth in a planned series of brief explanatory notes on the spacecraft and its subsystems.)

Part 12 – Infrared Interferometer Spectrometer and Radiometer (IRIS)

Jupiter, with its colorful and distinctive bands of clouds, has puzzled man for many centuries. Why are the bands, known as zones (light) and belts (dark), so well-defined? What determines their colors? How deep is the cloud cover? What lies beneath it? Does Jupiter have a solid surface at all?

Voyager's experiment with the most tongue-twisting name, the infrared interferometer spectrometer and radiometer – usually known simply as IRIS – is designed to probe the atmosphere of the Giant Planet for answers to some of these questions. Jupiter's satellites and the Saturanian and Uranian systems will be explored as well.

Each distinct chemical compound has a unique spectrum. As a result, by measuring the infrared and visible radiation both given off (emitted) and reflected from an object, a great deal can be learned about atmospheric gas composition, abundances, clouds, hazes, temperatures, dynamics, and heat balance.

Scientific Objectives

Hydrogen, deuterium, helium, methane, ammonia, ethane, and acetylene have been identified in the Jovian atmosphere above the upper cloud deck. Deeper measurements (through holes in the clouds) indicate the presence of carbon monoxide, water, deuterated methane, germane and phosphene as well. Many of these constituents are also

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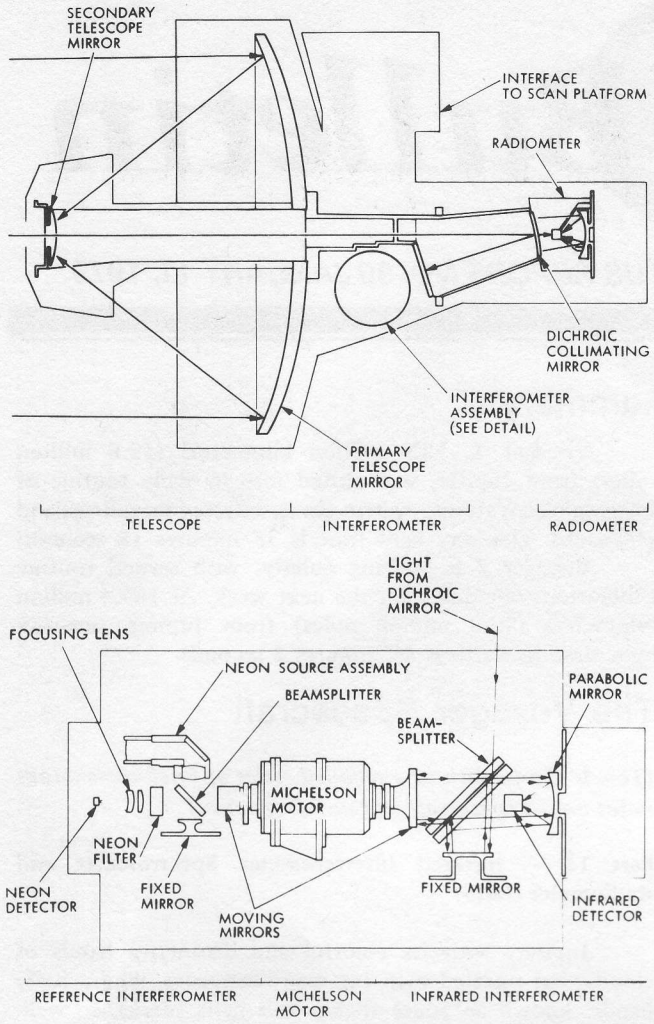


The Voyager Spacecraft – IRIS (contd)

present on Saturn. Titan, one of the satellites of Saturn, is also known to have a substantial atmosphere. Voyager's IRIS will measure the atmospheric composition and structure on all of these bodies. Once the composition of an atmosphere is determined, knowledge of its absorption properties can be used to measure temperatures at various depths as a function of pressure. The clouds appear to form well-defined layers in the atmosphere, and above these are tenuous hazes. The ease with which these structures absorb or emit infrared radiation and light will permit a determination of cloud depth, as well as state (ice or aerosol).

Jupiter's banding has been observed for centuries. Why has it persisted for so long? Most theories explain the bands as the result of convection – circulation of warm and cool air. Jupiter appears to have an internal heat source, and a relation appears to exist between cloud color and temperature in both the zones and belts. Although Jupiter's banding runs east and west, considerable north-south motions of the atmosphere also exist and will be probed.

Many ices and minerals have distinctive spectral characteristics. Using these signatures, composition and temperature maps of the satellites will be constructed. Together with images also obtained by Voyager, these can be used to investigate the geology and evolution of these bodies. Comparisons among the satellites will be made; it is already known, for example, that the more dense Jovian satellites are closer to the planet, while the less dense are farther out. Such variations of satellite properties with distance from Jupiter may lead to further understanding of the formation of each, and possibly of the planet itself. Perhaps more than the large Galilean satellites, tiny Amalthea, closest to the parent planet, may provide insight into its own origin, since it is too small to have undergone extensive internal changes, such as the melting that has resulted in the earth's molten core.

Instrumentation

IRIS will measure the intensity and spectral distribution of infrared radiation reflected and emitted by atmospheres and surfaces. Light is gathered by a 50-centimeter (20-inch) diameter telescope and directed into the optics of the instrument. Within the optics assembly, the light strikes a mirror which reflects wavelengths longer than 2.5 microns into the interferometer and transmits those shorter than 2.0 microns into the radiometer. This mirror is called a dichroic collimator; that is, it separates the lightwave into various wavelengths (colors) and reflects these as parallel rays.

The radiometer responds to solar radiation in the spectral range from 0.3 to 2 microns; that is, from the ultraviolet through the visible spectrum and into the near infrared.

The interferometer assembly actually contains two interferometers: a reference instrument having an internal source of neon light, and the infrared instrument itself, which responds to radiation in the range of 2.5 to 50 microns (the mid- to far infrared).

The infrared light reflected into the interferometer assembly by the dichroic collimator is further split into two beams; one of these is focussed on a fixed mirror, while the other is focussed on a moving mirror. The beams are reflected from these mirrors and recombined so that they interfere with each other, and the resulting intensity is measured. If the moving mirror is in a position so that the recombined beams are out of step, then this intensity is zero; if the mirror position is such that the recombined beams are in step, then the intensity is large. The variations of this intensity as the position of the moving mirror changes represent the interferogram, which is the output of the instrument.

To help prepare the interferogram for radio transmission, the reference interferometer is used. One mirror in this interferometer moves with the moving mirror of the infrared interferometer. In the same way that the infrared radiation is handled in the infrared interferometer, the light from a single red neon line is passed through the reference interferometer to provide a regularly varying (sinusoidal) signal; the instants at which this crosses zero are used to control the motion of the mirrors and to determine when the light intensity in the infrared interferometer is measured. The resulting series of pulses is sent to Earth, where it is processed by computer to provide the infrared spectrum.

Mounted on the scan platform, the IRIS assembly weighs about 18 kilograms (40 pounds), including the telescope, radiometer, interferometers, electronics, and power supply. It uses about 14 watts of power of which 8 watts are used for temperature control. The instrument was designed and fabricated by Texas Instruments, Inc., Dallas, Texas.

Investigators

R. A. Hanel, of NASA's Goddard Space Flight Center (GSFC), Greenbelt, Maryland, is the principal investigator for the IRIS. Co-investigators are B. Conrath, V. Kunde, P. Lowman, W. Maguire, J. Pearl, J. Pirraglia, and R. Samuelson (all from GSFC), S. Kumar (JPL), C. Ponnamperuma (University of Maryland), D. Gautier (Paris Observatory, France), and P. Gierasch (Cornell University, Ithaca, New York).

Voyager Bulletin

MISSION STATUS REPORT NO. 31 JANUARY 19, 1979

Mission Highlights

Detail Increases

As Voyager 1 draws nearer the giant planet, the cameras are showing increasing detail. The circulation patterns, especially around the Great Red Spot, are becoming more discernible. Much attention will be focussed on the Red Spot itself to determine its wave pattern – is the center swirling while the edges are quiet, or is the center quiet while the edges flow? Now known to be purely an atmospheric feature, the Red Spot was once thought to be anchored to a surface feature, which would have explained its longevity. Its size has decreased in recent years.

Increasing detail in the belts (dark bands) and zones (light bands) also shows interesting features. The zones are thought to be rising, while the belts are descending. At their interfaces, wind shears result, accounting for the turbulent features observed in these areas.

"Hot spots" can be seen below the Red Spot, to the left and right. Specific spacecraft sequences will target to these and other interesting features.

Voyager 1 Activities

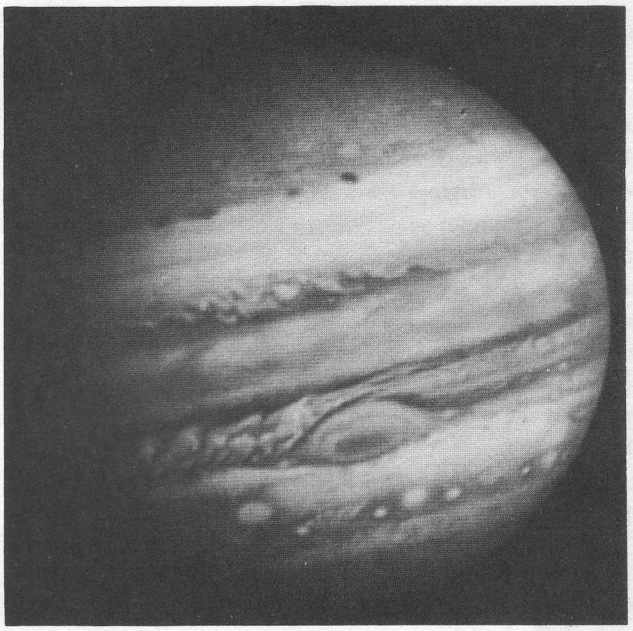
The daily system scans, infrared mapping, ultraviolet searches, and imaging sequences of the observatory phase will continue next week. "Tweaking" of the scan platform pointing is planned to "fine tune" the centering of the planet in the instruments' fields of view.

The IRIS is operating well after its warming sequence in late December.

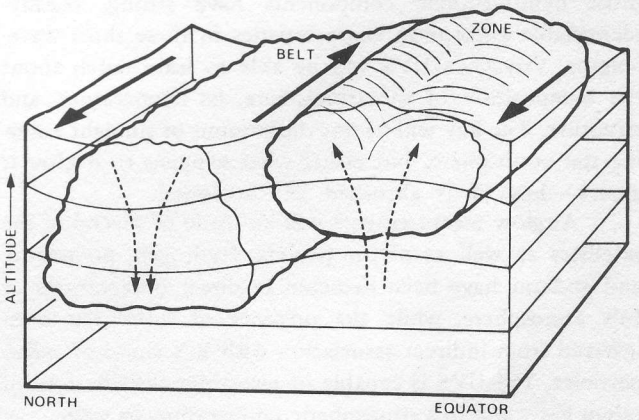
Voyager 2

The trailing spacecraft remains relatively quiet, with routine tests and calibrations at cruise level. The IRIS has undergone a heating period to maintain good performance in the interferometer's Michelson motor.

Another test of a link between the Stanford radio telescope and the planetary radio astronomy antennas is planned for the near future in further analysis of the PRA's capability should Voyager 2's remaining radio receiver fail.



WIND SHEARS – An atmospheric system larger than Earth and more than 300 years old, the Great Red Spot remains a mystery and a challenge to Voyager's instruments. In this picture taken by Voyager 1 on January 9 through a blue filter, swirling, storm-like features possibly associated with wind shear can be seen both to the left and above the Red Spot. Analysis of motions of the features will lead to a better understanding of Jovian weather. The spacecraft was 54 million kilometers (34 million miles) from the planet at this point.



CIRCULATION – Current models of Jupiter's atmosphere theorize rising zones and descending belts.

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The Voyager Spacecraft

Part 13 — Ultraviolet Spectrometer

Hydrogen, helium, and methane — hardly a mixture of which one would wish to take a deep breath. Yet these are the expected major constituents of the atmospheres at the outer planets.

Voyager's ultraviolet spectrometer (UVS) will study the composition and structure of the atmospheres of Jupiter, Saturn, possibly Uranus, and their satellites, as well as stellar sources of ultraviolet radiation.

Scientific Goals

Two rather different techniques have been developed for spectroscopically probing planetary atmospheres from the Earth or passing spacecraft (as opposed to landers or penetrators). Airglow observations require a large collecting area for maximum sensitivity to weak emissions found high in the atmospheres where collisions between the gas atoms and molecules are infrequent. Occultation measurements, on the other hand, require an instrument which can look directly at the Sun, using it as a source of ultraviolet radiation to measure absorption and scattering by the atmosphere as the spacecraft moves into the planet's or satellite's shadow.

Voyager's UVS combines these two types of spectrometers with a common detector system.

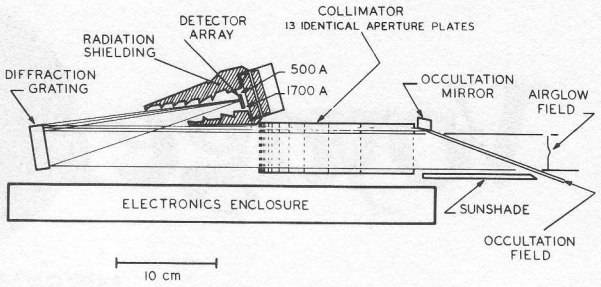
Airglow observations will measure the distribution of atomic hydrogen and helium in the upper atmosphere by recording the resonance scattering of sunlight. Resonance scattering arises by atoms or molecules absorbing solar radiation at characteristic wavelengths and re-radiating at the same wavelength. This differs from fluorescence in which the activating wavelength is absorbed and the energy is emitted at longer wavelengths.

As the Sun is occulted by the planet (blocked from the spacecraft's view), the planet's atmosphere moves slowly between the Sun and the instrument. Since all common atmospheric components have strong, readily-identifiable absorption characteristics in these short wavelengths, Voyager's UVS will be able to learn much about the composition of the atmosphere, its temperature, and structure. The key will be not the amount of sunlight entering the atmosphere, but rather what happens to it after it enters — how it is absorbed and scattered.

Airglow measurements will be made of several of the satellites as well as of the planets. Hydrogen, potassium, and sodium have been detected in direct observations of Io's atmosphere, while the presence of sulfur has been inferred from indirect association with Io's cloud of sulfur particles. The UVS is capable of measuring distributions of minor gases and Io's atmospheric temperature, as well.

Auroral activity on Ganymede, another of Jupiter's Galilean satellites, may confirm water ice on the satellite's surface by permitting measurements of atomic oxygen.

The UVS will contribute to mapping the torus clouds around the planets and satellites, especially the hydrogen cloud around Io. The "circumference" and out-of-plane thickness of the cloud are of great interest; that is, how far does it extend above and below the plane of Io's orbit? In mid-February, the slit will be oriented both perpendicular and parallel to the orbital plane in special spacecraft maneuvers to help measure the extent of the gas clouds around Jupiter.



The UVS will also observe Io's "flux tube", the region of interaction between Io and Jupiter's magnetic field. Spectral analysis of Jupiter's atmosphere where the flux tube contacts the planet should be revealing.

Grating Spectrometer

The UVS detects and measures ultraviolet radiation in the range from 500 to 1700 Angstroms, at 128 contiguous intervals. Included in this range are the hydrogen Lyman series molecular hydrogen, helium, methane, acetylene, ethane, and other atmospheric hydrocarbons.

Light enters the UVS instrument through an aperture which has two fields of view (FOVs). During the occultation mode, the main FOV (0.9 by 0.1 degree) for airglow measurements is shielded by the sunshade. The occultation FOV (0.9 by 0.3 degree) is also offset 20 degrees from the airglow FOV so that the instrument can be pointed at the Sun with no damage from direct sunlight to the airglow FOV and the other scan platform instruments.

After entering the aperture, the light passes through a set of 13 identical aperture plates (the mechanical collimator). (Wavelengths shorter than 1050 Angstroms cannot be transmitted by an optical collimator, but can be by the mechanical one.) The collimator restricts the field of view to the concave diffraction grating which has been ruled at 540 lines per millimeter by diamond point. The radiation is reflected from the grating and dispersed onto the ultraviolet detector where it is converted to electrical pulses indicating the number of photons (measurable units of light) at particular wavelengths in the extreme ultraviolet.

Mounted on the scan platform, the UVS weighs 4.5 kilograms (10 pounds) and was fabricated by TRW Systems, Redondo Beach, California, under contract to the designer, Kitt Peak National Observatory, Tucson, Arizona.

Investigators

A. L. Broadfoot of Kitt Peak National Observatory is the UVS principal investigator. Co-investigators are M.J.S. Belton (Kitt Peak), J. L. Bertaux and J. E. Blamont (Service d'Aeronomie du CNRS, Paris, France), S. K. Atreya and T. M. Donahue (University of Michigan), R. M. Goody and M. B. McElroy (Harvard University), A. Dalgarno (Harvard College Observatory), J. C. McConnell (York University, Ontario, Canada), H. W. Moos (Johns Hopkins University), B. R. Sandel and D. E. Shemansky (University of Arizona), and D. F. Strobel (Naval Research Laboratory, Washington, D.C.).

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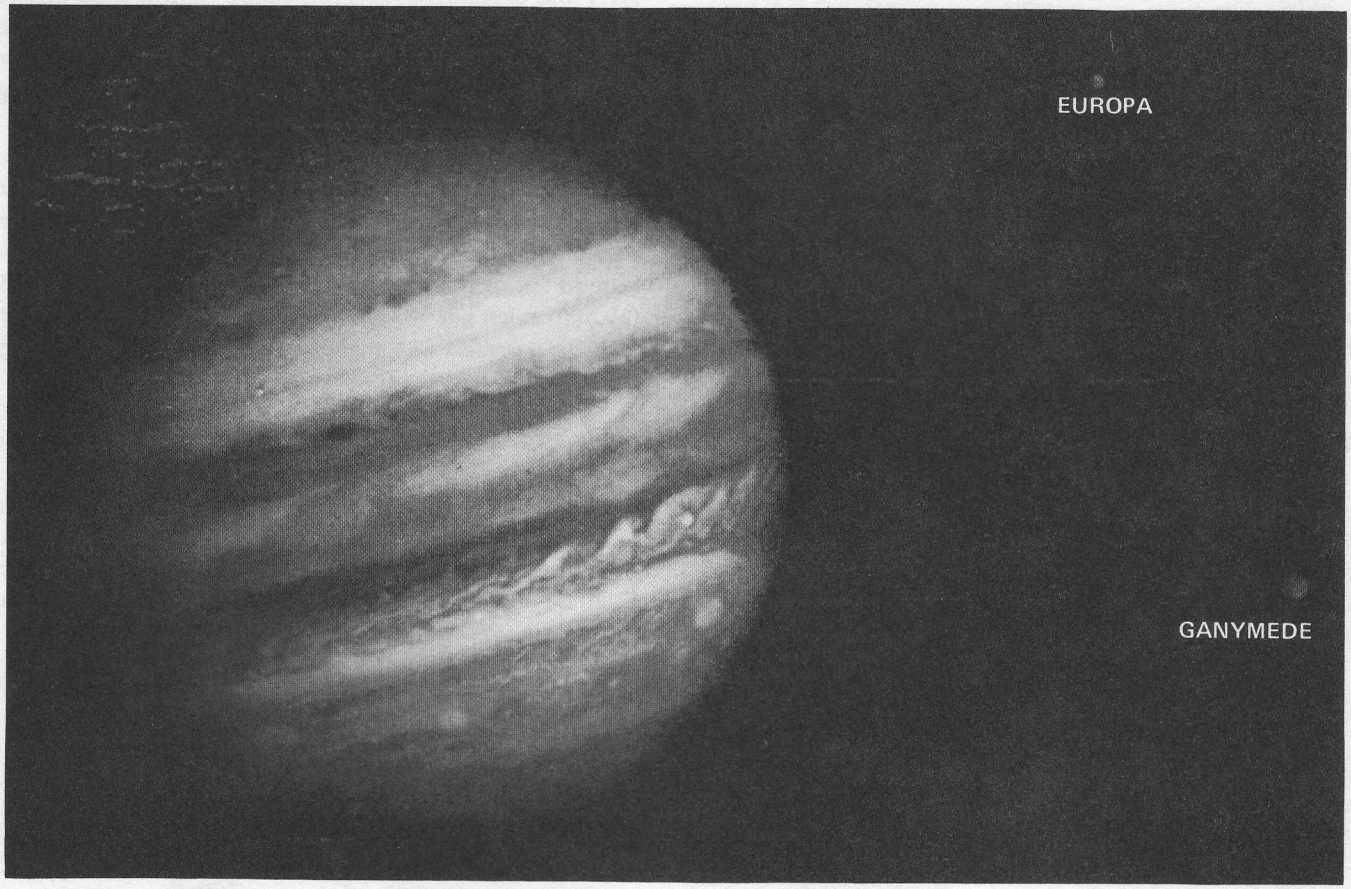
MISSION STATUS REPORT NO. 32 JANUARY 26, 1979



JUPITER'S MOONS — Voyager 1's cameras captured two of Jupiter's moons, Ganymede and Europa, in this picture taken the morning of January 17, 1979, from a distance of 47 million kilometers (29 million miles). Despite the small images of the moons, this photo and others are beginning to show details on the satellites not seen before in Earth-based photos.

Europa, an unusually bright satellite slightly smaller than the Moon, is revealed to have a dark equatorial band. Although scientists believe Europa is rocky, its surface appears to be covered with a layer of ice or frost of undetermined thickness.

Larger than the planet Mercury, Ganymede is believed to be composed of a mixture of rock and water ice with a surface of ice or frost with a scattering of darker soil. This photo shows only the darker side of Ganymede; the hidden half seen in other photos of the big satellite is marked by a large bright region.

Rapid changes in Jupiter's atmosphere are being observed — some occurring within 20 hours (two Jovian days). An example is changes in the long series of wave-like patterns trailing Jupiter's Great Red Spot (far right). The bright zone stretching across the northern hemisphere may be clouds of frozen ammonia similar to cirrus clouds of water ice in Earth's atmosphere.

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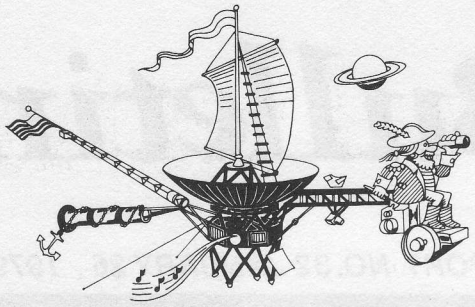


U.S.S. VOYAGER

Encounter Minus 38 Days and Closing

The days are ticking off rapidly as Voyager 1 closes in on its first major objective, the Jovian system. The "observatory" phase of Voyager 1's mission draws to a close January 30, with the last daily routine systems scans on January 25. These scans have provided valuable background measurements of the Jovian system which will help in later data analysis.

Using the images and data of the observatory phase, a target selection working group has identified the most interesting features to be examined for the highest science return, and computer sequences to target to these areas are being completed.

Trajectory Correction Maneuver January 29

On January 29, Voyager 1 will fire its hydrazine thrusters to adjust its flight path. One more trajectory correction maneuver is scheduled for February 20 to put the spacecraft exactly on target for its audience with the giant planet in early March.

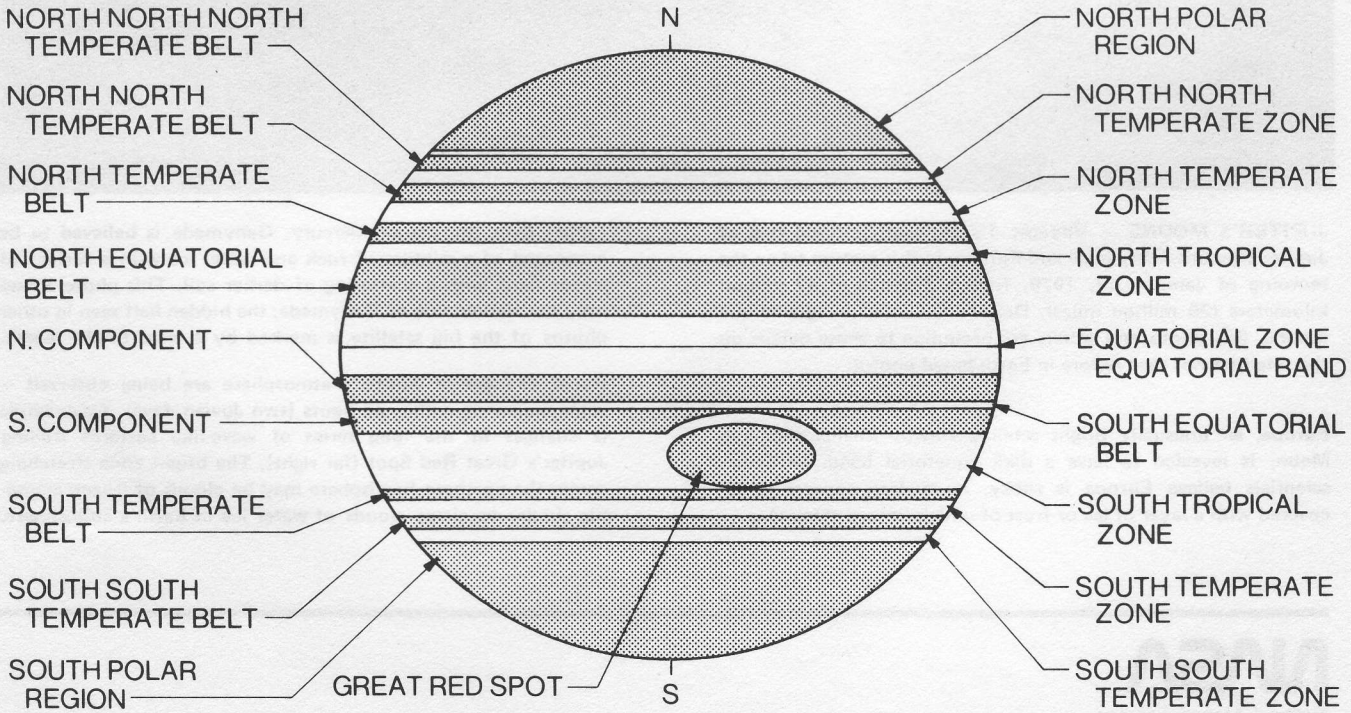
While radiometric data precisely determines the position of the spacecraft in relation to Earth, optical navigation is needed to pinpoint the locations and orbital paths of the satellites. This is accomplished by pointing the camera at a specific satellite and taking a long-exposure image.

Intensive Imaging

On January 30, Voyager 1 will begin a 4-day period of intensive Jupiter imaging, returning pictures in real-time (not tape-recorded for later playback as in the observatory phase). Shuttering every 96 seconds for 100 hours, Voyager 1 will capture 10 Jovian rotations. Narrow-angle images will be taken through three different filters every three degrees of rotation to allow color reconstruction of what will essentially be a "movie" of Jupiter's rapidly changing atmosphere.

At the start of the sequence, the spacecraft will be about 34.7 million kilometers (21.6 million miles) from the planet and Jupiter's disk will fill about 480 pixels (picture elements) of the 800-pixel imaging frame. Travelling with a heliocentric velocity of about 13.2 kilometers per second (29,600 miles per hour), Voyager 1 will gain about 3.9 million kilometers (2.4 million miles) on the planet during the 4-day period of intensive imaging.

Since the imaging data will be returned in real time at the highest data rate available (115,200 bits per second) over X-band, the Deep Space Network will provide continuous 24-hour a day coverage with the 64-meter antennas (only these antennas are capable of receiving this data rate). Voyager 2 and other space probes will be covered by the five 26-meter antennas and one 34-meter antenna (Goldstone) of the Deep Space Network.



MAJOR FEATURES OF JUPITER – Ground-based and Pioneer observations of the giant planet have allowed scientists to label Jupiter's major features for reference purposes. Voyager is already rewriting the textbooks, however, as its cameras record the ever-changing atmosphere. The once-wide south tropical zone is presently considerably narrower, while the north temperate zones have spread. Voyager is also identifying smaller features, such as plumes and hot spots, and tracking their changes.

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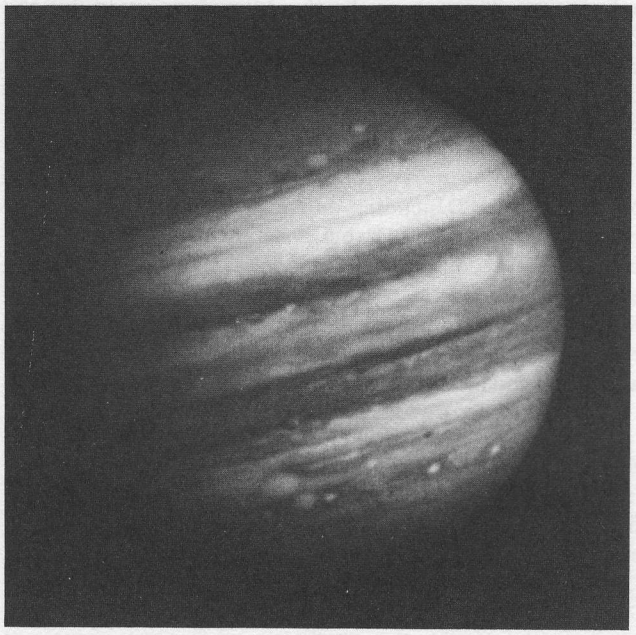
MISSION STATUS REPORT NO. 33 FEBRUARY 2, 1979



IO CASTS ITS SHADOW – As Jupiter's satellite Io (lower center) passes before the giant planet, its shadow (left) can be seen falling on the planet's face. Io is traveling from left to right in its one-and-three-quarter-day orbit around the planet. Even from this great distance the image of Io shows dark poles and a bright equatorial region. Voyager 1 was 47 million kilometers (29 million miles) from the planet when this image was taken through a blue filter on January 17, 1979.

The Voyager Spacecraft

Part 14 – Imaging

Until about 1960, photography of Jupiter was hit or miss – if some time was available at the telescope on a clear night, and if someone was inclined, they might take a picture of Jupiter. The next opportunity might not come for weeks.

But the visible disk of Jupiter is all "weather" – random photos of the planet amount to little more than taking an occasional picture of clouds somewhere on Earth and then trying to forecast the weather.

In the early 1960's, astronomers began a new routine – an observation program in which they took pictures of Jupiter every hour all night long, on every night that was good for viewing. In ten years, astronomers learned more about Jupiter than they had learned in all the preceding time.

Now, in the next eight months, NASA's two Voyagers will take tens of thousands of high-resolution photographs of the Jovian system, free of interference from the distortion caused by Earth's bubbling, boiling atmosphere.

More Than Pretty Pictures

The photos returned by Voyager thus far show a pretty tangerine-and-white-striped ball. But there's more than meets the eye, and the list of objectives is long. The Voyager imaging investigators will study:

Planetary Atmosphere

- Global circulation, including convection, vorticity and divergence
- Horizontal and vertical structure of the visible clouds and their relationship to the belted appearance and dynamical properties
- Vertical structure of high, optically thin scattering layers
- Anomalous features such as the Great Red Spot, south equatorial belt disturbances, plumes, hot spots, and white ovals
- Cloud coloration

Satellites

- Comparative geology of the Galilean satellites at less than 15-kilometer resolution
- Geologic structure of several satellites at high resolution (about 1 kilometer)
- Chromophores on Io
- Atmospheres
- Size and shape of the satellites by direct measurement
- Direction of the spin axes and period of rotation of the satellites; establish coordinate systems for the larger satellites

System

- Optical scattering properties of the planets and satellites at several wavelengths and phase angles
- Novel physical phenomena such as the "flux tube," meteors ("fireballs"), lightning, auroras, or satellite shadows.

(contd)

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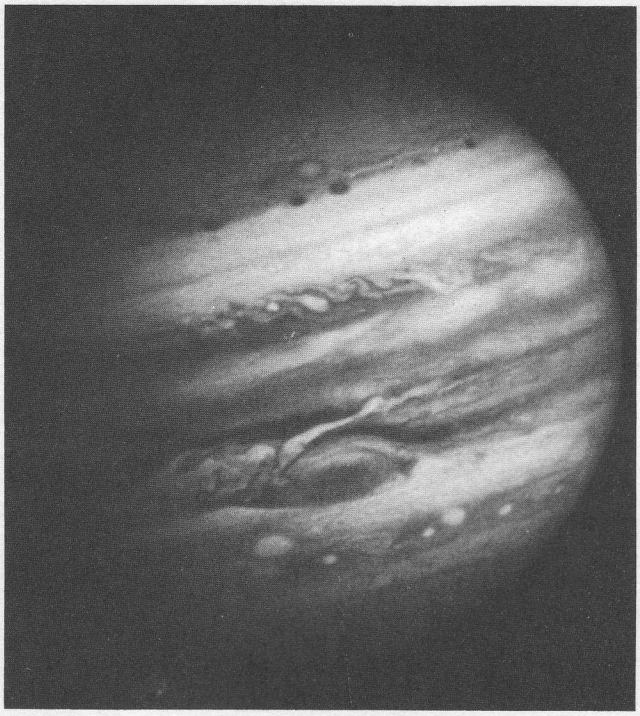
Encounter Minus 31 Days

Recorded Mission Status (213) 354-7237
Status Bulletin Editor (213) 354-4438



RED SPOT VORTICITY — The Great Red Spot shows prominently (below center), surrounded by a remarkable complex region of the giant planet's atmosphere. An elongated yellow cloud within the Great Red Spot is swirling around the spot's interior boundary in a counterclockwise direction with a period of a little less than six days, confirming the whirlpool-like circulation that astronomers have suspected from ground-based photographs. Ganymede, Jupiter's largest satellite, can be seen to the lower left of the planet. Ganymede is larger than Mercury. This black and white image was taken through a blue filter on January 24, 1979 while Voyager was 40 million kilometers (25 million miles) from Jupiter.

How Do They Do That?

Each spacecraft carries a 200-mm, f/3.5 wide-angle camera and a 1500-mm, f/8.5 narrow-angle (telephoto) camera that can be shuttered singly, alternately, or simultaneously at exposure times from 0.005 to 15.36 seconds, or even longer in special modes.

Each camera assembly includes an eight-position filter wheel, including clear (2), violet, blue, orange, green (2), and ultraviolet for the narrow-angle, and blue, clear, violet, sodium D, green, orange, and two wavelengths of methane for the wide-angle. The sensitivity of the filters ranges from 3450 (ultraviolet) to 6200 Angstroms (visible orange). Visible light encompasses the range from about 3800 to 6800 Angstroms.

Color reconstruction is done by combining images taken through different filters; for example, blue, green and orange. Certain features, such as the Great Red Spot, are more prominent and show more contrast in some filters (blue, for example), than in others (orange) due to the reflectivity.

The cameras are slow-scan vidicon designs that use a one-inch selenium-sulfur vidicon to convert the optical image into electrical signals. The subject is scanned one line at a time, and each fragment of light registered (called a picture element or "pixel") is converted into electrical signals for transmission to Earth. After acquisition by the Deep Space Network, the signals are processed, manipulated by a computer system to adjust for the planet's rotation between shuttering, and reconstructed with a laser system on standard photographic film.

The frame area is 800 scan lines by 800 pixels, or 640,000 pixels. Depending on the spacecraft data rate, the readout time for each frame is 48 seconds (at 115.2 kilobits) to 480 seconds (at 21.6 kilobits). The frames may be edited to a slower data rate if necessary (for example, if high winds or rain precluded use of a 64-meter antenna to receive the 115.2 kbps data). The pictures are read out and appear on the monitors one line at a time.

Twenty days before closest approach, about mid-February, the disk of Jupiter will exceed the 0.4-degree field of view of the narrow-angle camera, and the 3.2-degree field of view of the wide-angle camera will be required to continue full-disk imaging.

Mosaics of the Jovian system will be sequenced, mapping the planet, the satellites, and features of interest such as the Great Red Spot, white ovals, and hot spots.

The surface resolution criterion for maps of the satellites is the same as for the Earth-orbiting satellite Landsat (1:5,000,000 is the largest acceptable scale). Reference maps at a scale of at least 1:25,000,000 will be produced for Io, Europa, Ganymede, and Callisto, with high resolution maps of Io and Ganymede at 1:1,000,000 scale. (In comparison, U.S. Geological Survey 15-minute topographical maps are at a scale of 1:62,500 and one inch equals nearly one mile.) The highest resolution near each encounter will be 1 kilometer or less.

Mounted on the scan platform, the imaging system weighs about 38.2 kilograms (84 pounds). The vidicons were produced by General Electrodynamics Corporation, Dallas, Texas, while Xerox Corporation, Electro-Optical Systems, Pasadena, California, assembled the imaging electronics.

VOYAGER IMAGING TEAM

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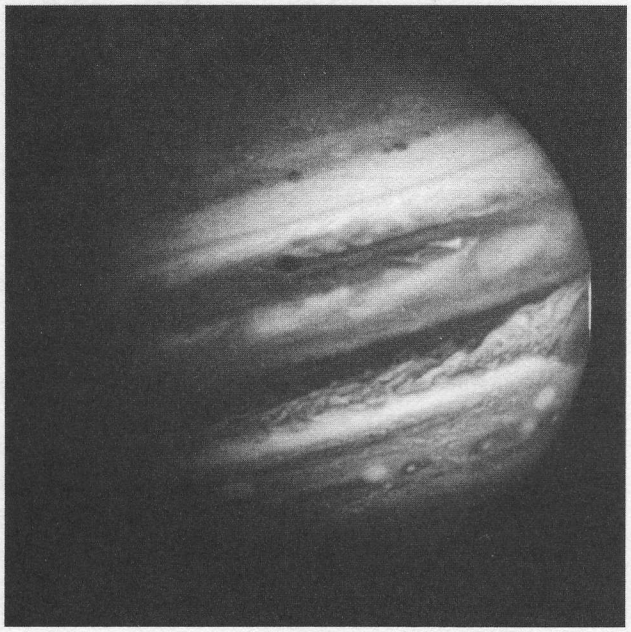
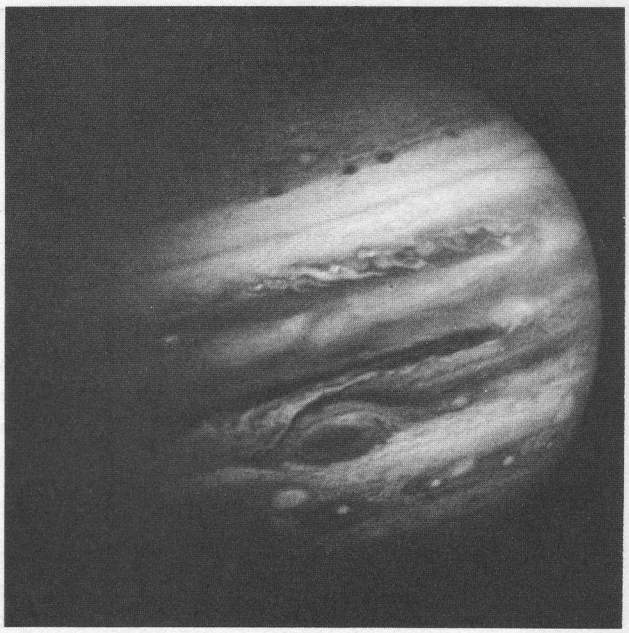
Voyager Bulletin

MISSION STATUS REPORT NO. 34 FEBRUARY 9, 1979



HIGH-SPEED JET STREAM — This photo of Jupiter taken January 27, 1979, by Voyager 1 shows a thin brown band in the light zone north of the Great Red Spot (extreme right), thought to be the location of a high-speed jet stream similar to Earth's jet stream. The spacecraft was 37.5 million kilometers (23.3 million miles) from the planet at the time of this photo. Voyager 1 will take more than 15,000 pictures of Jupiter and its major satellites by the time it has completed its three-month encounter with the giant planet.



COLD SPOT — Generally, dark features on Jupiter are warm, while light features are cold; the exception is the Great Red Spot, the coldest place on the planet. Believed to soar about 25 kilometers (15 miles) above the surrounding clouds, the Great Red Spot covers a portion of the planet about three times the size of Earth. With this and other pictures, scientists are able to detect counterclockwise motion within the spot. This picture of Jupiter was taken January 29, 1979, by Voyager 1 when it was 35.6 million kilometers (22 million miles) from the planet.

2 x 2 Mosaics Begin

Marked by the end of 100 hours of intensive imaging and the beginning of planetary mosaics, Voyager 1 moved into the next phase of its Jupiter observations on February 3.

As the spacecraft draws near, the disk of the planet grows, filling much of the field of view of the narrow angle camera (0.4 degree). Since spacecraft motion creates a pointing offset moving from one side of the imaging frame to the other, mosaics are now necessary to ensure full coverage of the planet.

Voyager 1 will be taking three-color 2 x 2 mosaics of the planet every two hours (every 72 degrees of the planet's rotation) through February 21. By then, the disk will have grown from about 0.24 degree on February 3 to about 0.61 degree, and 3 x 3 mosaics will begin. Some wide-angle images will be taken through the methane filter during the current mission phase.

The 2 x 2 mosaics consist of shuttering once through each of three filters (violet, orange, and green) at four different points, moving the scan platform in a square pattern,

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Recorded Mission Status (213) 354-7237
Status Bulletin Editor (213) 354-4438

for a total of 12 pictures. When fitted together, each set of 12 will make one color image of the full disk of Jupiter.

Processing of the imaging frames taken in a 100-hour period from January 30 to February 3 is underway. The result will be a color movie of multiple Jovian rotations.

Infrared Spectra Continue

Voyager 1 continues daily infrared spectra of Jupiter. During January, the infrared interferometer spectrometer (IRIS) acquired 74 hours of data on the infrared composition of the Jovian system.

Earth-based infrared images of the planet are being used to interpret the spacecraft data. The instrument onboard the spacecraft will not have good spatial resolution until the planet is much closer, as it still sees Jupiter as one source.

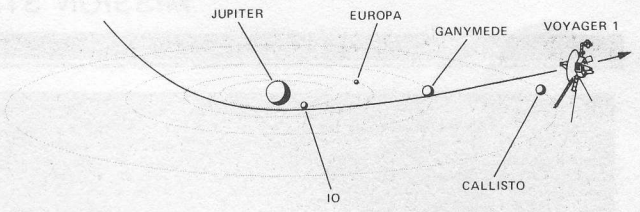
On January 26, the IRIS flash-off heater was turned on for the third heater cycle sequence. The heater remained on for 53 hours until January 29, when the heater was turned off, the instrument was turned on, and a dark sky calibration was performed. All systems are operating well.

Trajectory Correction Right On

Voyager 1's flight path was adjusted on January 29 with a 22-minute 36-second burn of the hydrazine thrusters. The ship's speed was changed by 4.145 meters a second (9.27 miles an hour). One more pre-Jupiter burn is scheduled for February 20, to "fine-tune" the spacecraft's aiming point, as knowledge of the orbits and ephemerides of the satellites are refined from Earth-based observations and optical navigation data.

Cruise and Target Maneuvers Allow Calibrations

A "mini" cruise science maneuver was performed by Voyager 1 on February 2 to allow calibration of several fields and particles instruments. The six-hour maneuver involved four complete roll turns followed by four complete yaw turns, during which the spacecraft was off celestial reference. The current celestial reference star is Canopus.



Voyager 1 March 5, 1979 Jupiter Encounter Trajectory

Rescheduled from December, a four-hour target maneuver on February 8 provided critical calibrations of the scan platform instruments. The routine maneuver requires several spacecraft turns to position the target plate (mounted on the spacecraft bus at an angle to the scan platform) in the Sun so that each instrument can "look" at the reflective plate as the platform maneuvers.

Satellite Drift Measurements Begin

The ultraviolet spectrometer (UVS), which has been scanning the entire Jovian system, has begun zeroing in on specific satellites. Within the next week, the UVS will look at Ganymede (February 8), Europa (February 11), Io (February 12), and Callisto (February 16), measuring ultraviolet emissions. The instrument's field of view slit will be pointed near the satellite and slowly moved across it. This permits measurements of both the satellite and any nearby gas clouds associated with that satellite.

Voyager 1 Enters Jovian Realm

With the crossing of the orbit of Jupiter's outermost known satellite on February 10, Voyager 1 will have physically entered the Jovian system. Tiny Sinope, some 23 million kilometers (15 million miles) from its "parent", circles the giant planet in retrograde orbit (clockwise). The satellite was discovered in 1914; its diameter is estimated at about 14 kilometers (8.7 miles).

Voyager Bulletin

MISSION STATUS REPORT NO. 35 FEBRUARY 19, 1979

Mission Highlights

As Jupiter looms larger and larger in Voyager 1's "eyes", anticipation and excitement are building back here at home. Members of Voyager's world-wide science community will be converging on the Jet Propulsion Laboratory, operations base for the mission, this week, taking up their short residences for the Encounter activities. A press conference at NASA Headquarters, Washington, D.C., on February 22 will present results to date, and the press corps will begin to descend on JPL February 26.

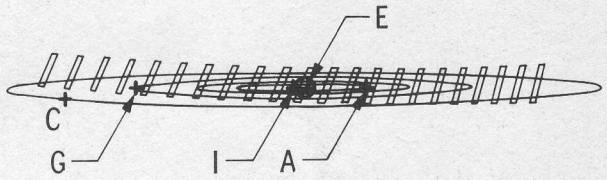
The flight team, meanwhile, continues flying the craft, checking it out, instructing it, and guiding it in for its close-up look at the giant planet and its satellites on March 4, 5, and 6.

UVS Scans System

Although the highest resolution images and closest approaches to the six bodies (Jupiter, Amalthea, Io, Europa, Ganymede, and Callisto) will not be obtained until the 39-hour Encounter period, much is being learned on the approach legs about the system as a whole.

Daily system scans by the ultraviolet spectrometer (UVS) sweep from the edges of one side of Callisto's orbit to the opposite side, searching for ultraviolet emission sources and distributions, and for gaseous clouds associated with some of the satellites. During these scans, the scan platform is stepped across the system at a very low rate (about 0.0052 degree per second), moving in either azimuth or elevation. Some of the slews produce a "sawtooth" pattern of coverage, while others step straight across the system, with the long axis of the instrument's field of view slit perpendicular to Jupiter's equatorial plane.

On February 18, the spacecraft was maneuvered so that the UVS slit was parallel rather than perpendicular to the plane of the ecliptic. The spacecraft was taken off Canopus and Sun lock and oriented by its gyro system in order to accomplish this "VERTSCAN" maneuver. The UVS then rastered across the system for about 7-1/2 hours, looking for contours of atomic hydrogen, taking the system's temperature, and looking for changes in temperature which might occur in the torus clouds. All of the data were recorded to be played back the next day.



UVS SYSTEM SCAN – The UVS is scanning the Galilean system from one edge of Callisto's orbit to the other. The satellites are (from left): Callisto, Ganymede, Io, Europa, and Amalthea.

First Callisto Images Targeted

The first targeted images of Callisto were taken through six filters on February 18, and are being processed through the mission and test imaging system (MTIS) and Image Processing Lab (IPL) at JPL. The resolution is calculated at about 140 kilometers per line pair, the highest resolution ever obtained of Callisto. Mapping of the satellite will continue this week.

Trajectory Correction Maneuver Scheduled

Voyager 1's final pre-Encounter trajectory correction is scheduled for February 20. The hydrazine thrusters will fire for approximately 2-1/4 minutes, changing the velocity and direction to deliver the spacecraft right to Jupiter's doorstep.

Knowledge of the exact paths of the spacecraft and target bodies is essential for loading the final pointing instructions for the scan platform. There is little margin for error, as the optical instrument's fields of view range from 0.10 degree to 3.5 degrees.

3 x 3 Mosaics to Begin

Jupiter has grown so large that 2 x 2 narrow angle mosaics, taken for the last 10 days, will soon no longer cover the disk, and 3 x 3 mosaics will begin on February 21. The disk will be covered in a grid of overlapping images taken at nine pointing positions.

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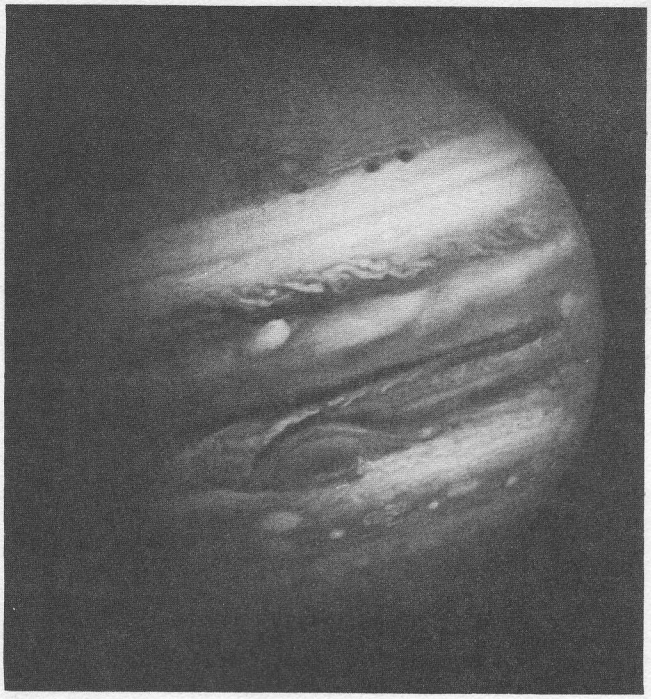
Encounter Minus 14 Days

Recorded Mission Status (213) 354-7237
Status Bulletin Editor (213) 354-4438
Public Information Office (213) 354-5011



CLOSER AND CLOSER – Objects as small as 600 kilometers (375 miles) across can be seen in this image taken by Voyager 1 on February 1, 1979, at a range of 32.7 million kilometers (20 million miles). Different colors in clouds around the Great Red Spot seem to imply that the clouds swirl around the spot at varying altitudes. The bright cloud in the equatorial region north of the Great Red Spot appears to be where bright clouds originate, then stream westward. The images also show apparently regular spacing between the small white spots in the southern hemisphere and similar positioning of dark spots in the northern hemisphere. A major activity will be to understand the form and structure of the spots and how they may relate to interactions between the atmospheric composition and its motions. The bright ovals south of the Great Red Spot were seen to form about 40 years ago, and have remained much the same ever since, while the Great Red Spot itself has been observed for hundreds of years.

Voyager 1 is accelerating toward Jupiter at a velocity of 13.2 kilometers per second (29,428 miles per hour), the gravity of the giant planet now influencing the spacecraft more than that of the Sun. Voyager 1 will continue to slowly pick up speed on its inbound leg, until closest approach on March 5 when the pull of Jupiter will accelerate the craft to about 36 kilometers per second (80,970 miles per hour)! And as the spacecraft flashes past the planet, the gravity will slow it gradually until in June it will be travelling towards Saturn at about 22.8 kilometers per second (51,000 miles per hour).

Activities Increasing

On February 21, the photopolarimeter (PPS) will point to the satellites, searching for sodium and mapping the distribution of this neutral atom as a function of Io's position and Jupiter's magnetic field.

Europa will pass behind the planet on February 22, affording an opportunity to observe an eclipse of the satellite. Measurements will be taken to determine any temperature changes on Europa as it emerges from the shadow of the planet. These changes could provide insight into the satellite's composition, as a rocky surface would react differently to the temperature change than would an icy one.

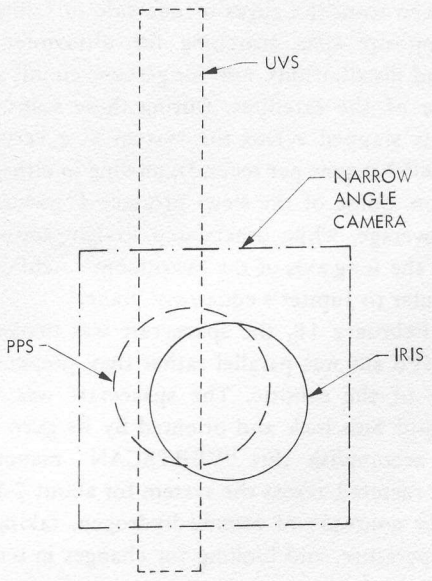
Searching for wind patterns travelling at greater than 100 meters per second (223.2 miles per hour), the imaging system will take a quick look at large regions of Jupiter on February 24. Lower wind speeds will be detected during closest approach.

On February 25, the first targeted image of Ganymede will be taken. Also, Voyager 1 is expected to cross the bow shock sometime next week, about February 26.

Summary

Voyager 1 is 15.2 million kilometers (9.5 million miles) from Jupiter, travelling with a heliocentric velocity of 13.2 kilometers per second (29,428 miles per hour). It has traced an arc through space of 988 million kilometers (614 million miles) since it left the Earth on September 5, 1977. It is now 644 million kilometers (400 million miles) from Earth, and radio signals take 35 minutes 42 seconds to cross this distance.

Voyager 2 is cruising quietly, 100 million kilometers (62 million miles) from Jupiter. Its heliocentric velocity has slowed to 11.5 kilometers per second (25,707 miles per hour), and its arc distance (the total distance travelled) is about 987 million kilometers (613 million miles). Radio signals take 31 minutes 40 seconds to travel the 571 million kilometers (355 million miles) between the spacecraft and Earth.



FIELDS OF VIEW – The FOV's of the optical instruments on Voyager's scan platform overlap so their data can be correlated.

Voyager Bulletin

MISSION STATUS REPORT NO. 36 FEBRUARY 23, 1979

IN TRANSIT – Voyager 1 took this photo of Jupiter, Io, and Europa on February 13, 1979. Io is about 350,000 kilometers (220,000 miles) above Jupiter's Great Red Spot, while Europa is about 600,000 kilometers (375,000 miles) above Jupiter's clouds. Although both satellites have about the same brightness, Io's color is very different from Europa's. Io's equatorial region show two types of material – dark orange, broken by several bright spots – producing a mottled appearance. The poles are darker and reddish. Preliminary evidence suggests color variations within and between the polar regions. Io's surface composition is unknown, but it may be a mixture of salts and sulfur. Europa is less strongly colored, although still relatively dark at short wavelengths. Markings on Europa are less evident than on the other satellites, although this picture shows darker regions toward the trailing half of the visible disk. Jupiter is about 20 million kilometers (12.4 million miles) from the spacecraft at the time of this photo. At this resolution (about 400 kilometers or 250 miles) there is evidence of circular motion in Jupiter's atmosphere. While the dominant large-scale motions are west-to-east, small-scale movement includes eddy-like circulation within and between the bands.

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Encounter Minus 10 Days

Recorded Mission Status (213) 354-7237
Status Bulletin Editor (213) 354-4438
Public Information Office (213) 354-5011

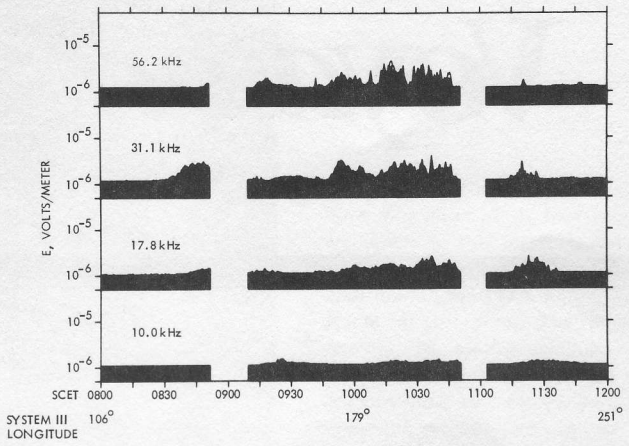
Mission Highlights

Voyager 1 is no longer "going" to Jupiter – it is there! Every instrument's data are showing strong indications of the planet's presence – and its presence is overwhelming.

Auroral-type activity around Io and Jupiter has been observed by the ultraviolet spectrometer (UVS). The gaseous torus cloud associated with Io does not seem to be composed of readily identifiable neutral atoms or singly ionized atoms.

The plasma wave instrument (PWS) is detecting very low frequency emissions (about 10 to 60 kiloHertz) that are not directly related to decametric emissions from Jupiter that have long been observed at Earth. The signals probably originate near or beyond the orbit of Io, and Voyager 1 should fly through this source area, obtaining direct information on the signals. The calculated power of the signals is about 1 billion watts, about the same as Earth's total radiated power. Jupiter's decametric radiation is about 100 billion watts. (These measurements assume isotropy, that is, that the same values can be measured in any direction.)

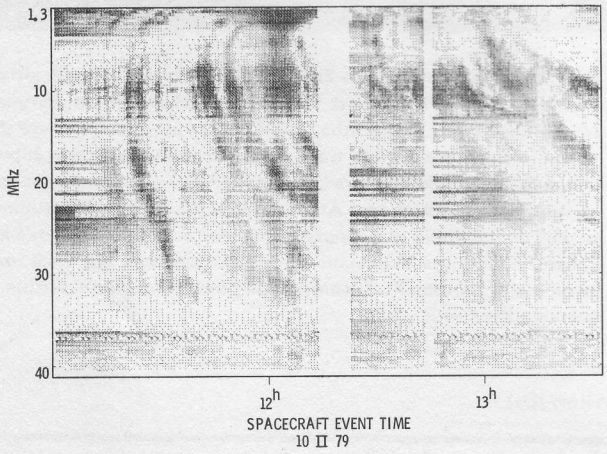
In related studies, the planetary radio astronomy (PRA) instrument is seeing arc structures in its radio spectrum data from about 30 megaHertz to less than 1 megaHertz. Jupiter's magnetic axis is offset from its spin axis by about 11°, so that the north magnetic pole is sometimes tilted toward Earth and the spacecraft. The PRA data shows arcs curving to the left before the magnetic pole tips toward Voyager, and to the right after tipping. Jupiter appears to be the source of the signals, but they are being affected in an area between the planet and the spacecraft – an area through which Voyager 1 is expected to fly.



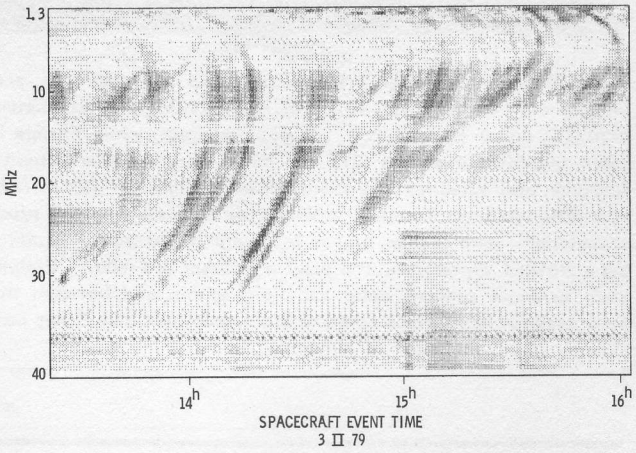
PWS – Voyager 1's plasma wave instrument is recording very low frequency radio emissions from Jupiter which appear to be related to the north and south magnetic poles. This spectrum was recorded on January 20 at about 44 million miles from the planet. The north magnetic pole passage occurs at about 210° longitude.

The magnetometers, low-energy charged particles (LECP) instrument, and plasma instrument are giving strong indications of nearing the bow shock, the interface between the solar wind and the planet's magnetosphere. Bow shock crossing may come sooner than predicted (February 26).

Images taken during January and early February have been processed into a recently released color movie. The rotation movie was compiled from intensive imaging on January 30 through February 3. Atmospheric changes (including current flows) through several rotations of Jupiter are visible, as well as satellites in transit around the planet. Counterclockwise rotation in the Great Red Spot is clearly visible.

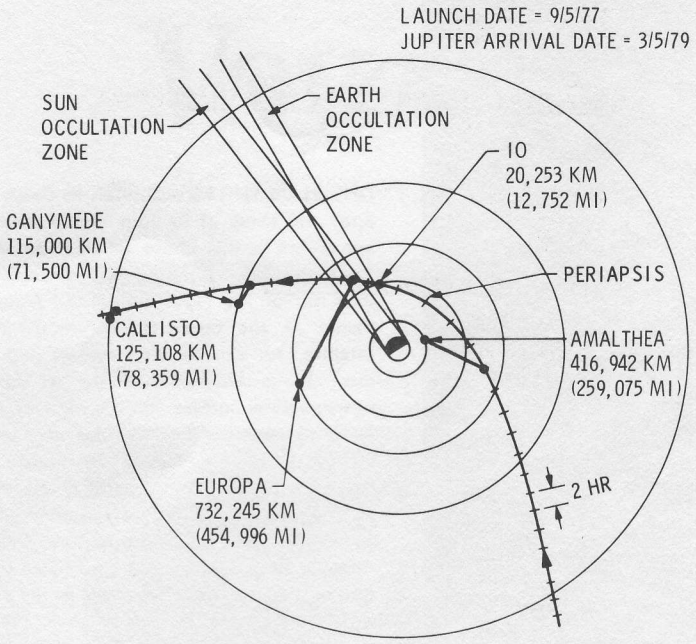


Before Northern Dipole Tip Passage (February 10)



After Northern Dipole Tip Passage (February 3)

ARCS – These radio spectra, collected by Voyager 1's PRA instrument on two different days, clearly show the arc structures associated with Jupiter's north magnetic pole each time it points toward the spacecraft.



A Miniature Solar System

With its thirteen, possibly fourteen, satellites, Jupiter forms what many liken to a miniature solar system. All of the inner satellites are denser and more massive than the other satellites. (Also true for the planets of the solar system – Mercury, Venus, Earth and Mars are all far more dense than Jupiter, Saturn, Uranus, Neptune, or Pluto.)

Voyager 1 will observe the five satellites closest to the planet: Amalthea, Io, Europa, Ganymede, and Callisto. Each is unique and intriguing.

Tiny **Amalthea**, about 120 to 240 km (75 to 150 mi) in diameter, is the innermost satellite, and orbits the planet once every 12 hours (approximately). In the past, it was speculated to be a captured asteroid, because of its small size and its reflectivity characteristics. Its average distance from the planet is 181,500 km (70,077 mi).

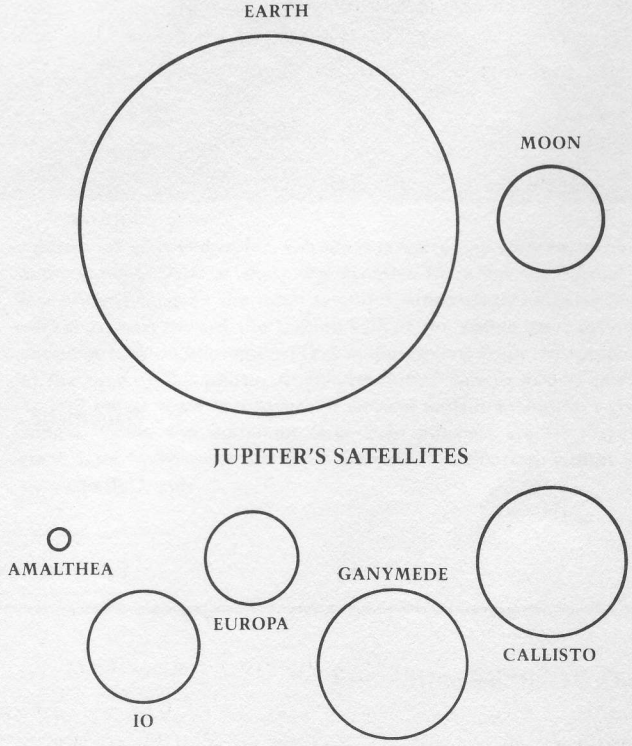
Voyager 1 is most interested in **Io**, so much so that it will risk Jupiter's intense radiation to get close to it. Voyager 2 will not attempt a close flyby of Io, and so will be exposed to less radiation. With reddish polar caps and a tenuous atmosphere, Io is also surrounded by a yellow glow – thought to be a cloud of sodium sputtered off the satellite's surface by particle bombardment.

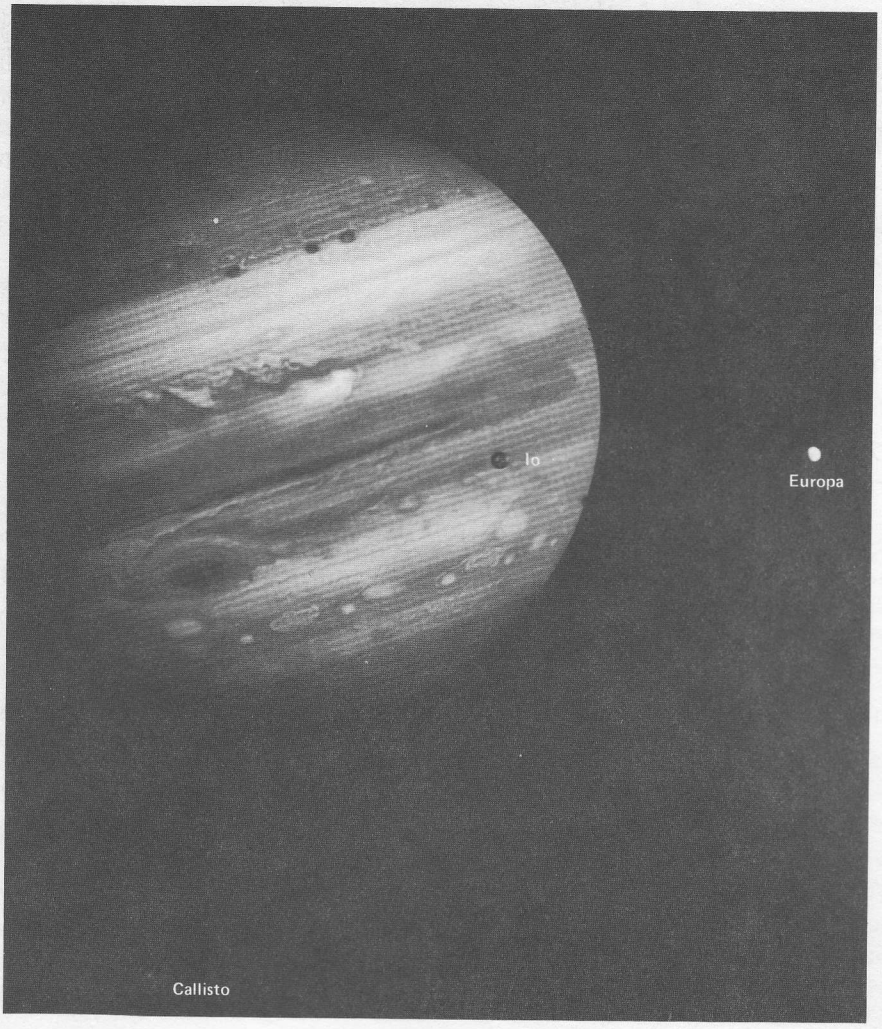
At about 5.9 R_J (Jupiter radii), Io is very much within the Jovian magnetosphere, and, indeed, seems to influence the pattern of Jupiter's decametric radio bursts. In addition, a region known as the Io "flux tube" is a magnetic link between the satellite's surface and the planet. Voyager 1 will spend about 4-1/2 minutes in this area as it flies beneath the satellite's south pole. Voyager 1's closest approach to Io will be from 20,253 km (12,752 mi) three hours after closest approach to Jupiter on March 5. Io is about the size of our moon (3636 km or 2259 mi), and is the third largest of the four Galilean satellites. It rotates about the planet in about 42-1/2 hours at a distance of 422,000 km.

Like Io, **Europa** appears to be a rocky body and recent pictures have shown a dark equatorial band. With a diameter of about 3066 km (1905 mi), it is slightly smaller than our moon and circles Jupiter in about 3-1/2 days from about 671,400 km. Voyager 1 will pass its closest to this satellite, 732,243 km (454,996 mi) on March 5.

Ganymede and **Callisto** are the second and third largest planetary satellites in the solar system (Saturn's satellite Titan is the largest). Both are larger than the planet Mercury. Ganymede is thought to be mostly liquid water with a mud-core and a crust of ice. With a diameter of about 5216 km (3241 mi), Ganymede circles Jupiter in about 7 days at an average distance of 1 million km (62 million mi). Voyager 1 will pass 115,000 km (71,500 mi) from Ganymede on March 5.

Callisto is thought to be half water, although its dark reflectivity indicates a rocky surface. Over 1.8 million miles from Jupiter, Ganymede makes one rotation in about 16 days 16-1/2 hours. Its diameter is about 4890 km (3039 mi). Voyager 1's closest look at Ganymede will be March 6 from about 125,108 km (78,359 mi).





ONE PLUS THREE – Jupiter, its Great Red Spot and three of its four largest satellites are visible in this photo taken February 5, 1979, by Voyager 1. The spacecraft was 28.4 million km (17.5 million mi) from the planet at the time. The innermost large satellite, Io, can be seen against Jupiter's disk. Io is distinguished by its bright, brown-yellow surface. To the right of Jupiter is the satellite Europa, also very bright but with fainter surface markings. The darkest satellite, Callisto (still nearly twice as bright as Earth's moon), is barely visible at the bottom left of the picture. Callisto shows a bright patch in its northern hemisphere. All three orbit Jupiter in the equatorial plane, and appear in their present position because Voyager is above the plane. All three satellites always show the same face to Jupiter – just as Earth's moon always shows us the same face. This photo shows the sides of the satellites that always face away from the planet.

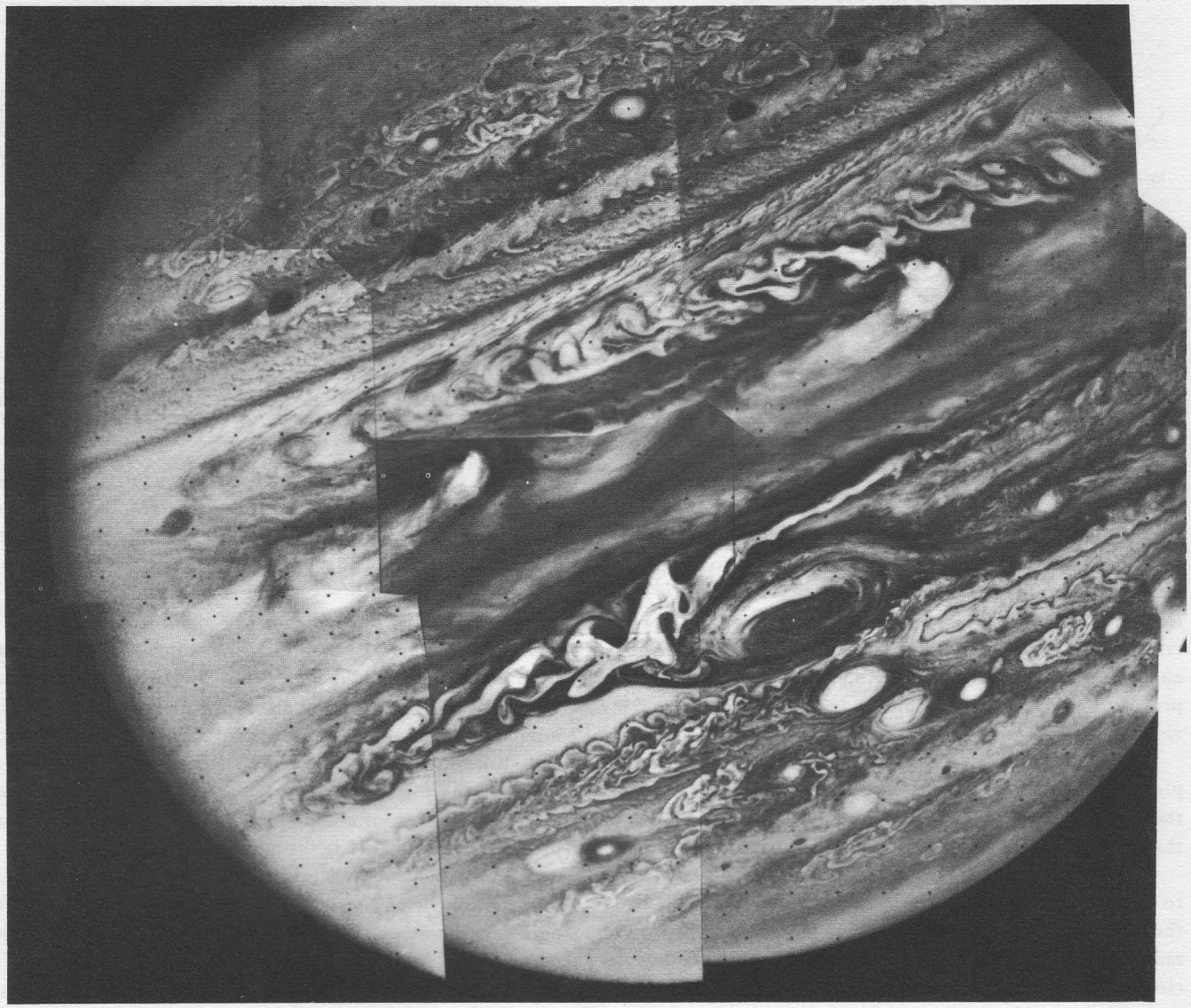
Closest Approaches

Body	Day*	Time (PST)*	Range
Amalthea	3/4	10:21p	416,942 km 259,075 mi
Jupiter	3/5	04:42a	280,000 km 174,000 mi
Io	3/5	07:50a	20,253 km 12,752 mi
Europa	3/5	11:19a	732,245 km 454,996 mi
Ganymede	3/5	06:52p	115,000 km 71,500 mi
Callisto	3/6	09:46a	125,108 km 78,359 mi

*Earth-received time

Voyager Bulletin

MISSION STATUS REPORT NO. 37 MARCH 2, 1979



COLOSSUS — Nine individual photos comprise this Jupiter mosaic, taken through a violet filter by Voyager 1 on February 26. At the time, the spacecraft was 7.8 million km (4.7 million mi) from the planet. Distortion of the mosaic, especially noticeable where portions of the limb have been fitted together, is caused by rotation of the planet during the 96-second intervals between individual frames. The complex structure of the cloud formations seen over the entire planet gives some hint of the equally complex motions in the Voyager time-lapse photography. The smallest atmospheric features seen in this view are approximately 140 km (85 mi) across.

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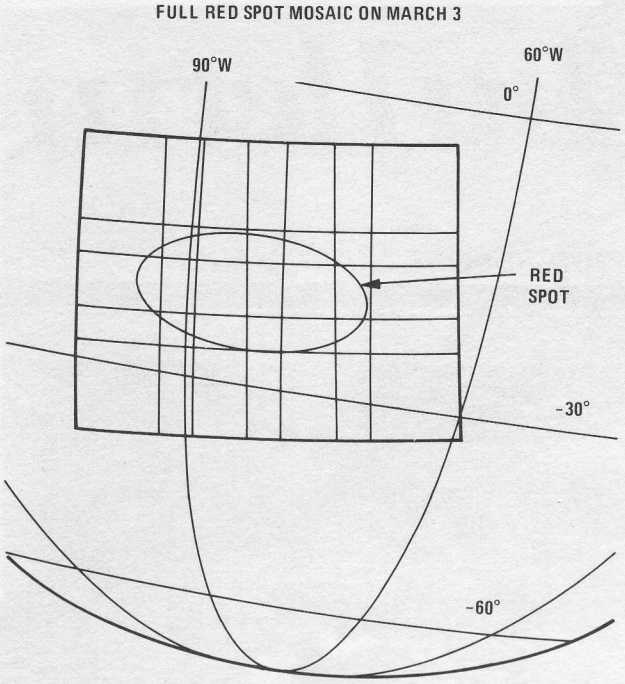
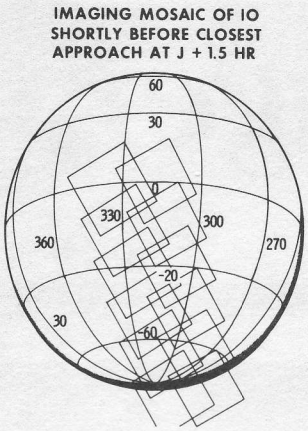
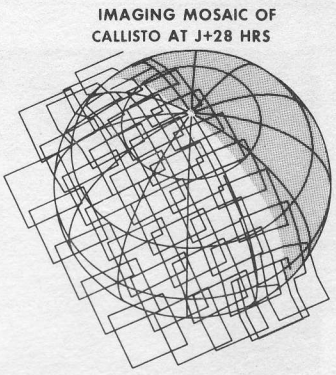
Encounter Minus 4 Days

Recorded Mission Status (213) 354-7237
Status Bulletin Editor (213) 354-4438
Public Information Office (213) 354-5011







MOSAICS – Voyager 1 will record many mosaics of Jupiter and its satellites, zeroing in on some features several times. Near midnight (PST) on March 3, for example, Voyager 1 will mosaic the Great Red Spot in a three-color 3 x 4 mosaic (above) from a distance of about 1.8 million km (1.1 million mi). The last mosaic of the Great Red Spot as a whole will begin about 8:51 p.m. (PST) on March 4, from a distance of 668,000 km (415,000 mi). Eighty-one imaging frames will be taken in 43 minutes, in a 3 x 9 two-color map. Mosaics will also provide high resolution maps of several of the satellites.

Earth, Sun Occultations

About 3-1/2 hours after closest approach to Jupiter, at about 8:23 a.m. (PST), Voyager 1 will begin to disappear behind the planet (as seen from Earth). First Earth and then the Sun will be blocked (occulted) from the spacecraft's view by Jupiter's bulk. The occultations, each lasting about two hours, overlap each other for about an hour, and provide opportunities for unique radio science and ultraviolet measurements.

As the spacecraft slips around into the shadow of the planet, it will track the virtual image of the Earth around the limb (disk edge) of the planet. Gyro drift turns, slower than a clock's hour hand, will follow the image.

Prior to the occultation, the spacecraft will be tuned to S-band high power and X-band low power to equalize the signals through the atmosphere. The distortion of the radio signals as they pass through increasing depths of clouds will tell much about the shape and concentration of materials in the ionosphere and atmosphere.

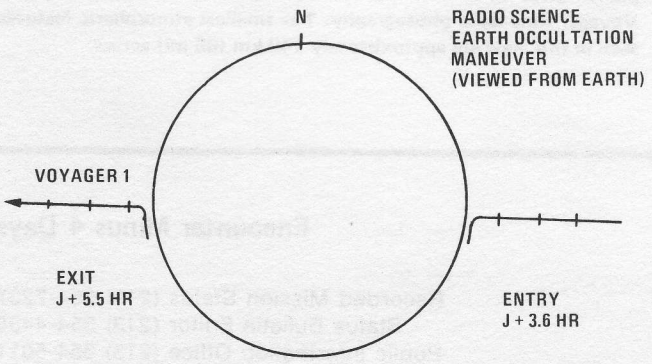
Then, in a series of commanded turns, the spacecraft will turn so that the ultraviolet spectrometer (UVS) slit is tangent to the planet's limb as Voyager, still in Earth occultation, enters the overlapping Sun occultation zone. The spacecraft antenna will then be pointing at the north limb.

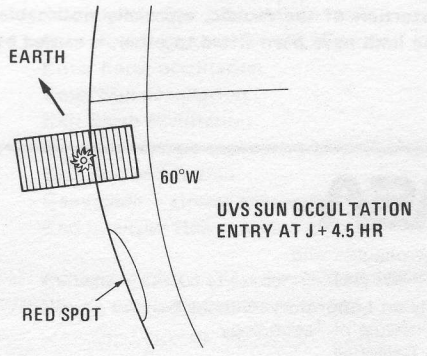
Then, the flash!

A focussing phenomenon for radio waves, the flash will last for about 1 second, during which the strength of the radio signals would increase about 100 times if there were no absorption of the signal by the atmosphere. The brief flash will allow measurement of atmospheric shape and absorption at a greater depth than possible at any other time. During this instant, Voyager 1 will be able to measure the concentration of components down to about the 4-bar pressure level with 100,000 times greater sensitivity.

And then, the spacecraft will exit Earth occultation, tracking the virtual image of the Earth until the spacecraft passes to the other side of the planet and reappears as seen from Earth.

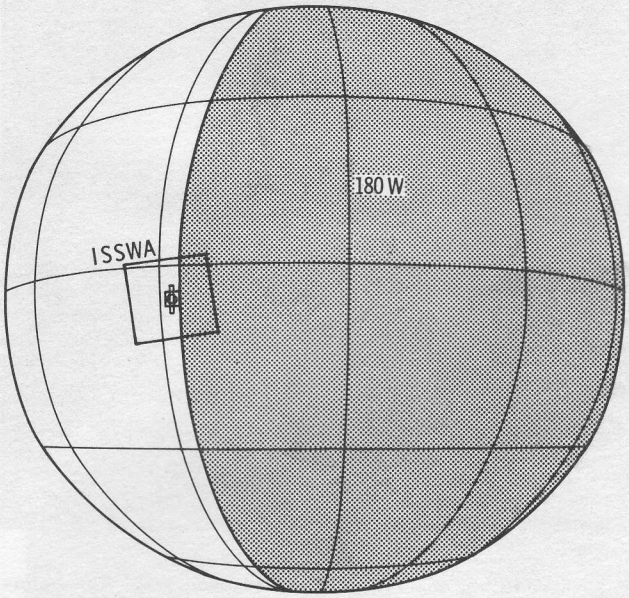
During the Sun occultation, the UVS will probe the deep atmosphere, determining gases, composition, and temperatures.



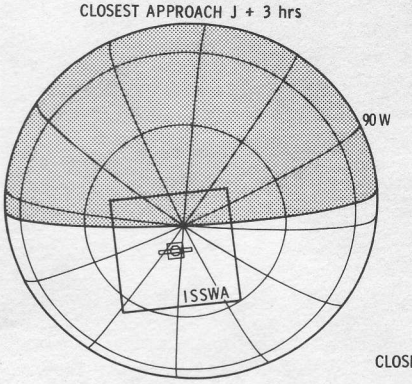


JUPITER

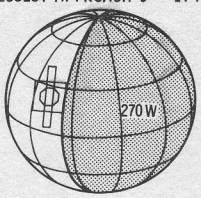
AT CLOSEST APPROACH MAR 5, 1979 (4:42 a.m. PST)



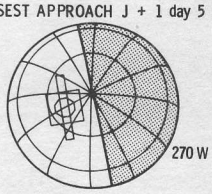
IO
CLOSEST APPROACH J + 3 hrs



GANYMEDE
CLOSEST APPROACH J + 14 hrs



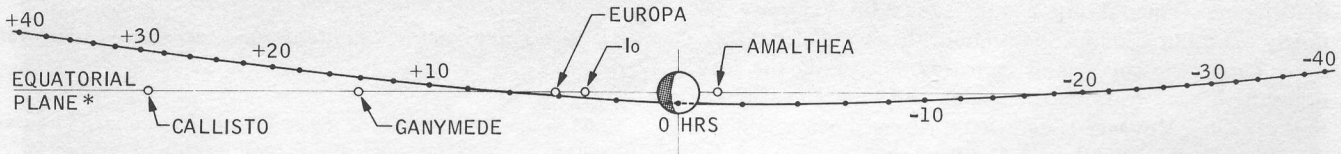
CALLISTO
CLOSEST APPROACH J + 1 day 5 hrs



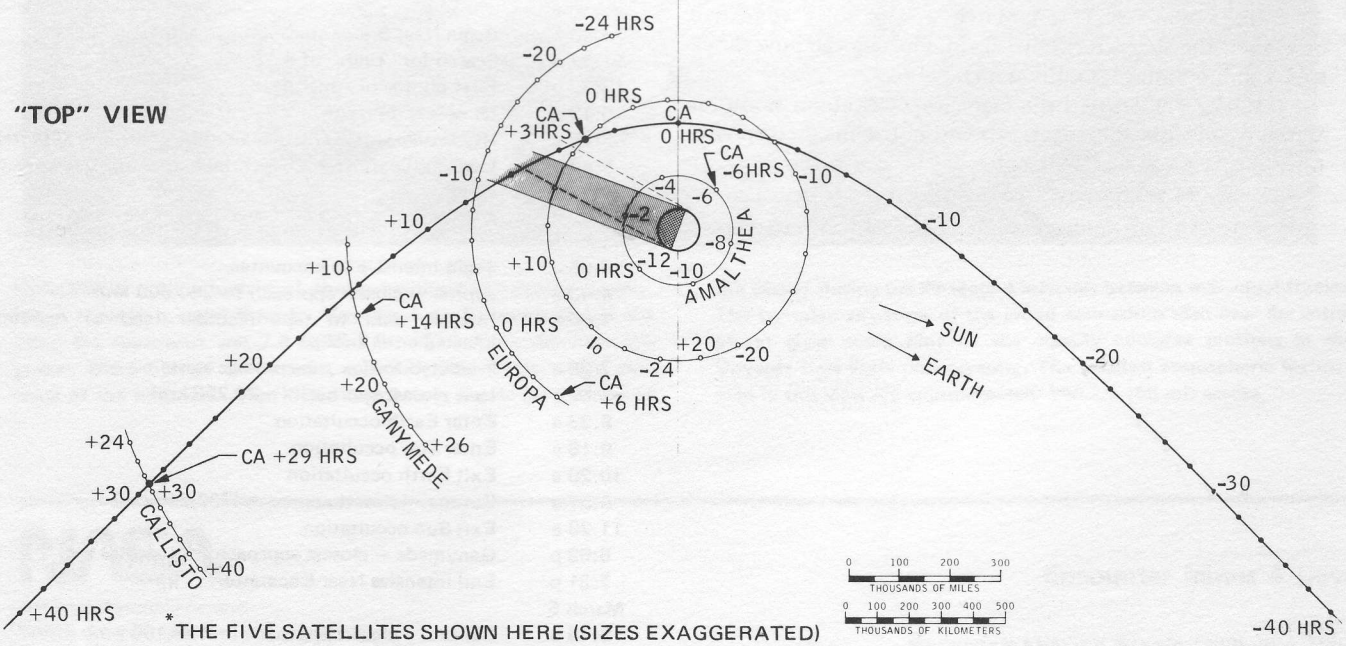
CLOSEST APPROACHES – Voyager 1 will make its closest approaches to Jupiter and its largest satellites on the morning of March 5, 1979, 18 months to the day after its launch. These computer generated plots show the spacecraft's view of the bodies at the times of closest approach. The instruments' fields of view are also shown (ISSWA is the FOV of the wide angle camera). The Red Spot will be on the opposite side of the planet when Voyager 1 gets its closest look at Jupiter at a point near the terminator (the dividing line between the lit and unlit sides of the planet). Three hours later, Voyager 1 will swing under the south pole of Io and spend about 4-1/2 minutes in the flux tube area. Closest approach to Ganymede eleven hours after Io will also be near the terminator. And 29 hours after its closest look at the giant planet, Voyager 1 will pass over the north pole of Callisto for its closest look at the outermost of the Galilean satellites.

VOYAGER 1 FLYBY OF JUPITER March 3 - 6, 1979

EDGE-ON VIEW

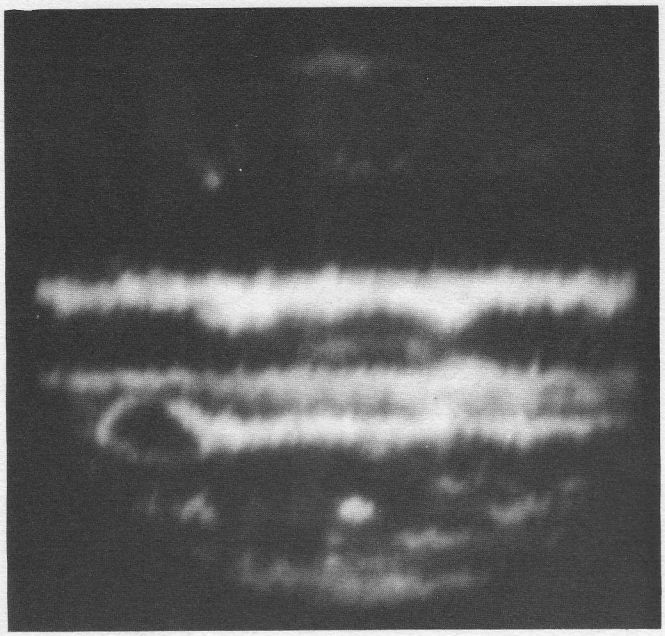


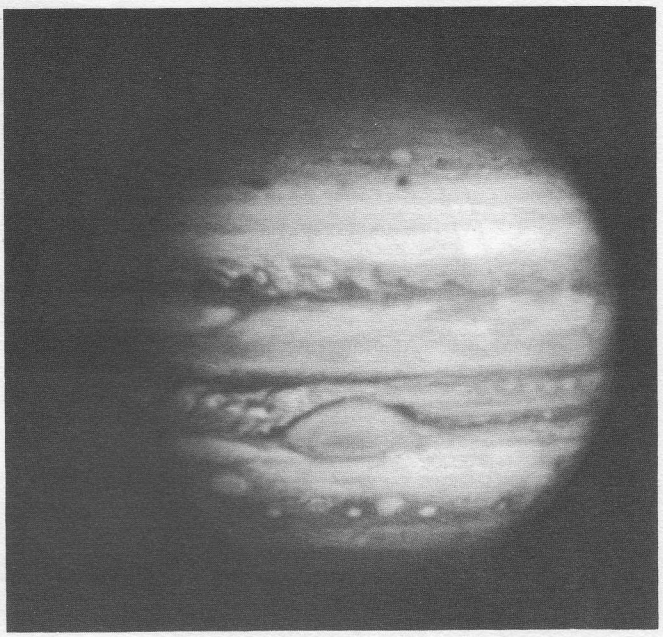
"TOP" VIEW



* THE FIVE SATELLITES SHOWN HERE (SIZES EXAGGERATED) LIE WITHIN 1/2 DEGREE OF JUPITER'S EQUATORIAL PLANE.

CA = CLOSEST APPROACH





5-MICRON HOT SPOTS – An infrared photograph of Jupiter from Earth (left) shows heat radiating from deep holes in the clouds of Jupiter. Bright spots in the image are regions of higher temperatures than the darker areas, and correspond to parts of the atmosphere that are relatively free of obscuring clouds. The Great Red Spot appears on the west (left) limb as a dark area encircled by a bright ring, indicating that the spot is cooler than surrounding regions. This supports other findings that the Great Red Spot may stand as high as 25 km (15 mi) above the surrounding clouds and is, therefore, cooler. The infrared photo was recorded on January 10, 1979, by the 200-inch Hale Telescope on Palomar Mountain, California (operated by the California Institute of Technology and the Carnegie Institution) by R. Terrile of JPL. The Voyager 1 photo at right was also taken January 10, about one hour after the infrared image. The spacecraft was about 53.8 million km (33.4 million mi) from the planet.

A Turbulent Solar Wind

Voyager 1 has met Jupiter's bow shock three times. The first crossing of the shock, the area where the supersonic solar wind responds to the presence of Jupiter's magnetosphere, came about 7 a.m. (PST) on February 28, nearly 6.1 million km (3.8 million mi) from the planet.

Later, the solar wind increased, squashing the magnetosphere back towards the planet, and six hours after the first crossing, Voyager 1 recorded the bow shock again, at a distance of 5.9 million km (3.7 million mi).

By 5 a.m. (PST) on March 1, the solar wind had overtaken the spacecraft once again, pushing the bow shock to 5.1 million km (3.2 million mi).

Voyager 1 crossed the magnetopause about noon on March 1, placing the spacecraft inside the magnetosphere for the first time.

Sampling of Encounter Activities

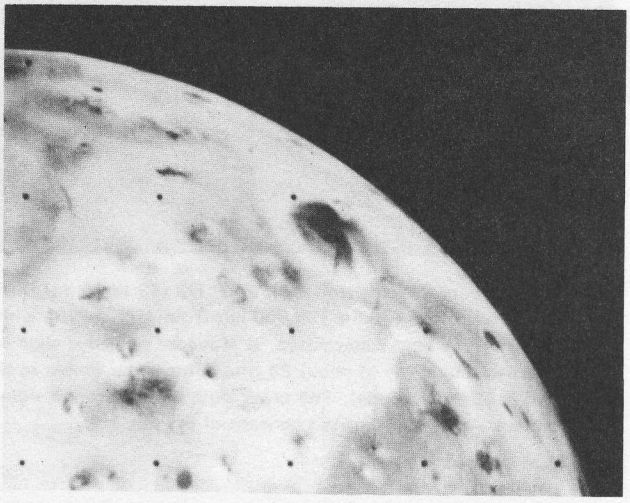
(Continuous observations by radio science, magnetometers, low-energy charged particle plasma, and cosmic ray investigations, as well as mapping by imaging cameras, photopolarimeter, ultraviolet and infrared spectrometers.)

All times are Pacific Standard Earth-received event start times.

March 3	
10:54 a	Plasma outflow measurements (spacecraft maneuver)
4:40 p	Io eclipse observations begin
March 4	
4:40 a	Begin Near Encounter intensive activity
11:37 a	Search for "rings" of dust
12:33 p	First photos of Amalthea
6:12 p	IR observations of first 5-micron hot spot (Jupiter)
5:48 p	IR, imaging of Earth occultation exit point (Jupiter)
8:48 p	Last full mosaic of Great Red Spot on day side of Jupiter
11:00 p	Amalthea – closest approach (~416,942 km)
March 5	
4:05 a	Begin intensive Io encounter
4:43 a	Jupiter – closest approach (~280,000 km)
7:00 a	Imaging data to tape recorder (end of real-time imaging until 2:22 p)
7:38 a	Predicted Io flux tube passage starts
7:52 a	Io – closest approach (~20,253 km)
8:23 a	Enter Earth occultation
9:16 a	Enter Sun occultation
10:20 a	Exit Earth occultation
9:57 a	Europa – closest approach (732,245 km)
11:28 a	Exit Sun occultation
6:53 p	Ganymede – closest approach (~115,000 km)
7:31 p	End intensive Near Encounter
March 6	
9:46 a	Callisto – closest approach (~125,108 km)
1:03 p	Search for new satellites

Voyager Bulletin

MISSION STATUS REPORT NO. 38 MARCH 12, 1979



THAR SHE BLOWS – These photos of a volcanic eruption on Jupiter's satellite Io present the evidence for the first active volcanic eruption ever observed on another body in the solar system. The photo at left, taken from a distance of 499,000 kilometers (310,000 miles) on March 4, shows a plume-like structure rising more than 100 kilometers (60 miles) above the surface, a cloud of material being produced by an active eruption (dark, fountain-like feature near the limb). At least four eruptions have been identified on Voyager 1 pictures and many more may yet be discovered on closer analysis.

On a nearly airless body like Io, particulate material thrown out of a volcano follows a ballistic trajectory, accounting for the dome-like shape of the top of the cloud, formed as particles reach the top of their flight path and begin to fall back. Spherical expansion of outflowing gas forms an even larger cloud surrounding the dust.

Several regions have been identified by the infrared instrument on Voyager 1 as being several hundred degrees Fahrenheit warmer than surrounding terrain, and correlated with the eruptions. The fact that several eruptions appear to be going on simultaneously makes Io the most active surface in the solar system and suggests to scientists that Io is undergoing continuous volcanism, revising downward the age of Io's surface once again.

Taken 1 hour, 52 minutes later, the photo at right shows plume-like structures rising more than 100 kilometers (60 miles) above the surface. Another characteristic of the observed volcanism is that it appears to be extremely explosive, with velocities more than 2,000 miles an hour (at least 1 kilometer per second) – more violent than any terrestrial volcanos like Etna, Vesuvius or Krakatoa.

Beyond its creators' wildest dreams, Voyager 1 has successfully met its first objectives, streaking past Jupiter, threading its way among the five astounding inner satellites, and discovering that Jupiter, like Saturn and Uranus, is a ringed planet.

". . . Superlatives fail us. The data speaks for itself."

Robert Frosch
Administrator
National Aeronautics and Space Administration

Alan Lovelace
Deputy Administrator
National Aeronautics and Space Administration

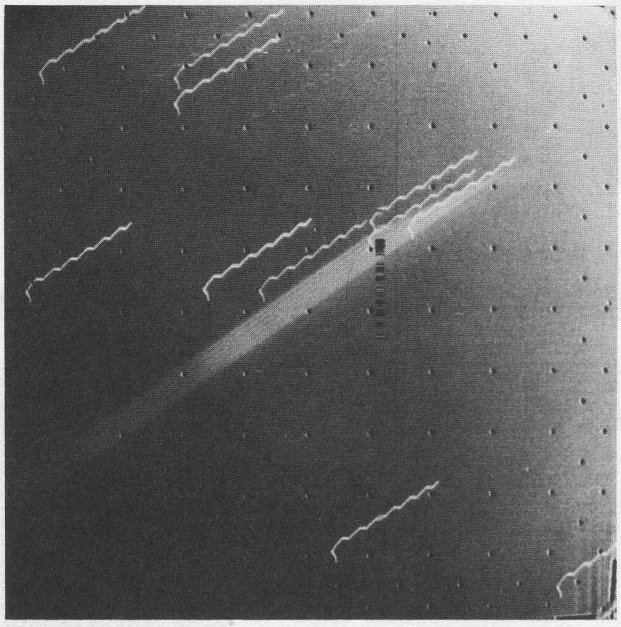
The wealth of information returned by its eleven scientific experiments will keep the analysts busy for years, especially when coupled with that being returned by its sister ship Voyager 2, now less than four months from its own trek through the Jovian system.

". . . spectacularly successful."

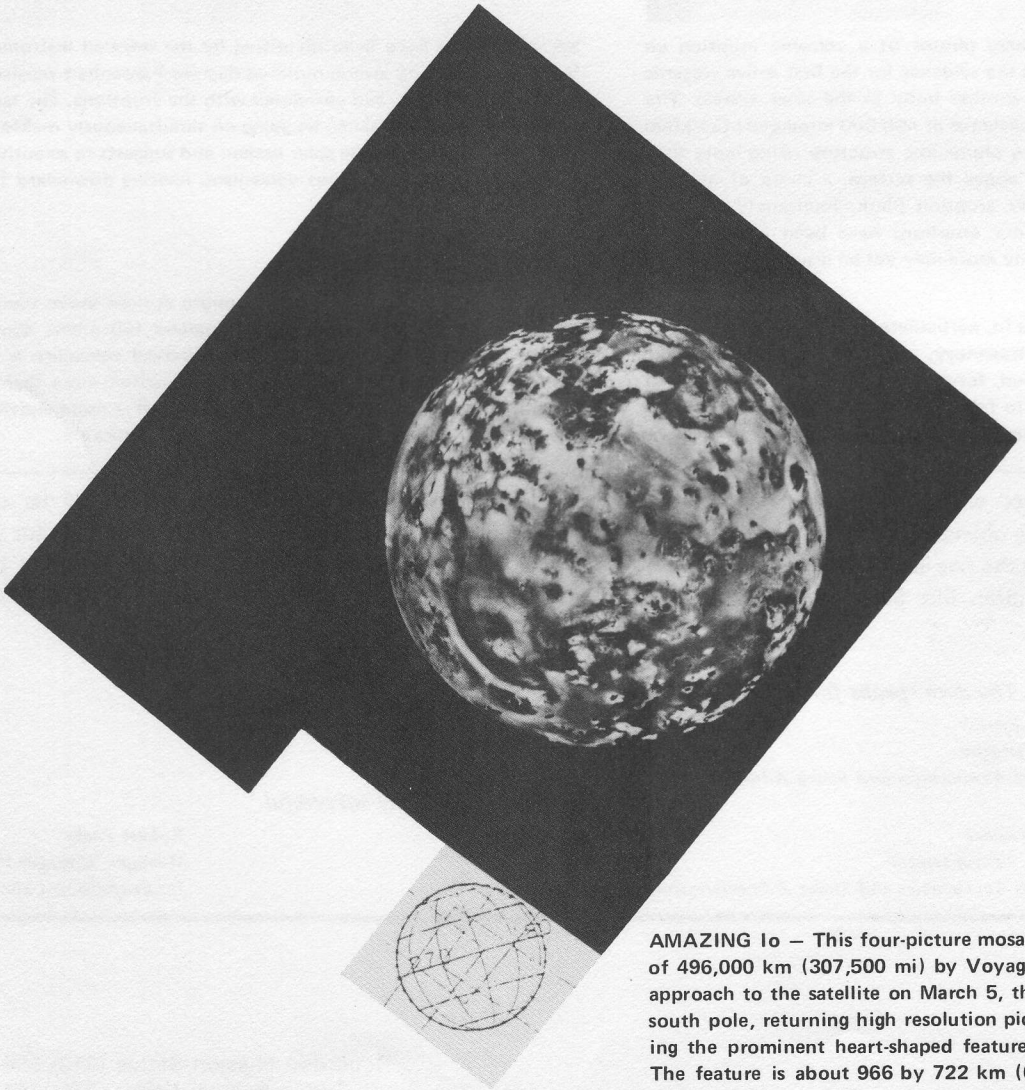
Robert Parks
Manager, Voyager Project
Jet Propulsion Laboratory

NASA
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Recorded Mission Status (213) 354-7237
Status Bulletin Editor (213) 354-4438
Public Information Office (213) 354-5011



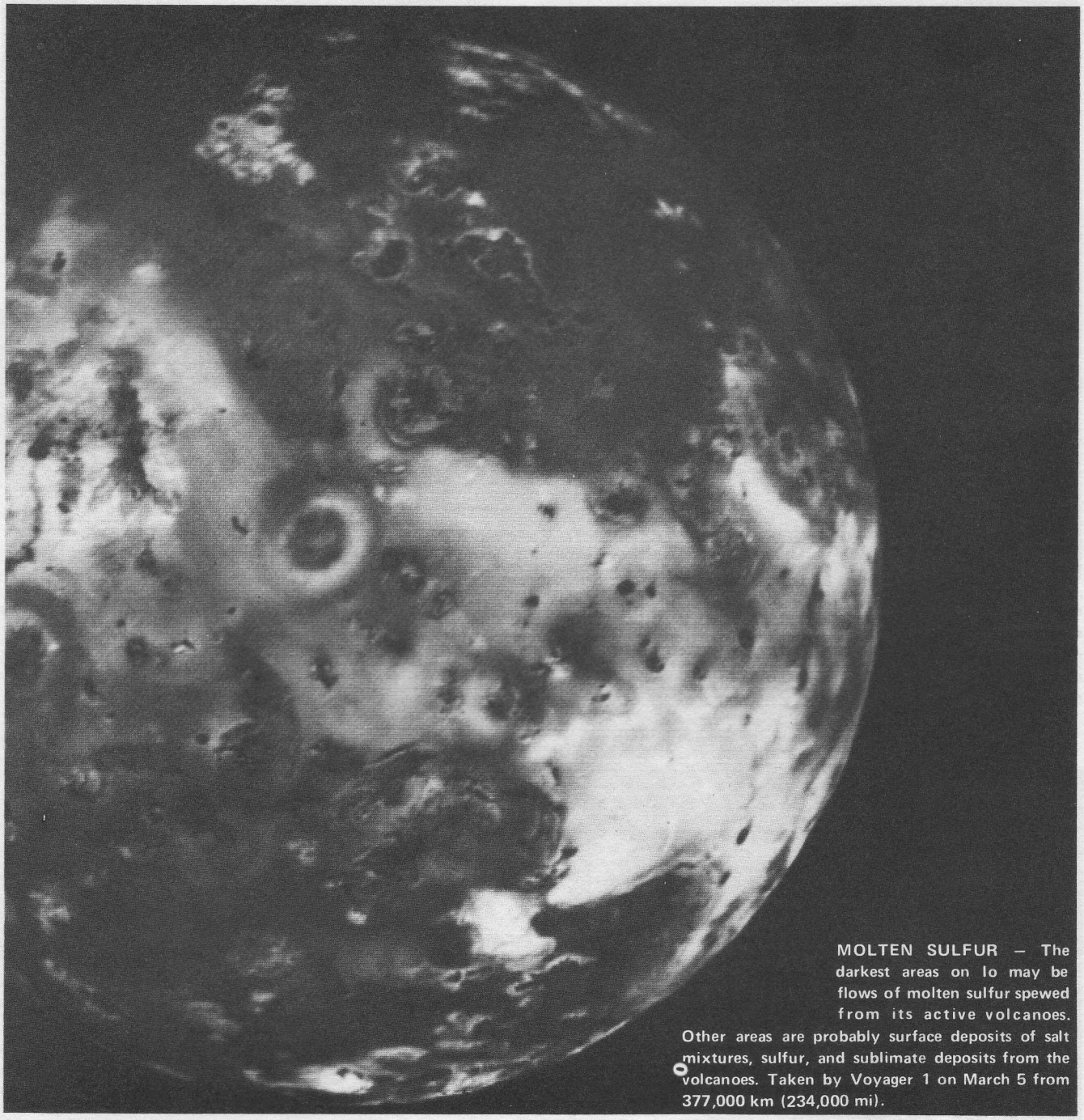
JUPITER – A RINGED PLANET – Voyager 1's narrow-angle camera detected this thin, flat ring of particles around Jupiter's equator on March 4. A time exposure of 11.2 minutes also captured star trails of the beehive cluster of 11 bright galaxies in the background. A slight nodding of the spacecraft due to its several long instrument booms – one is 43 feet long – accounts for the wavy motion of the star trails and the six exposures of the ring. Comprised of dark particles, the ring is 29 to 32 km (18 to 20 mi) thick, and was seen about 57,615 km (35,800 mi) from Jupiter. The width of the ring has not been determined, as Voyager viewed it edge on. It has a stellar magnitude of about 22 (the faintest star visible to the naked eye is 6th magnitude). The black dots are calibration points in the camera. At right, an artist's concept of the ring.



AMAZING Io – This four-picture mosaic of Io was taken at a range of 496,000 km (307,500 mi) by Voyager 1 on March 4. At closest approach to the satellite on March 5, the spacecraft flew under Io's south pole, returning high resolution pictures of the surface, including the prominent heart-shaped feature at lower left in this view. The feature is about 966 by 722 km (600 by 480 mi) across. The smallest features visible in this view are 10 km (6 mi) across.

Voyager Bulletin

MISSION STATUS REPORT NO. 39 MARCH 19, 1979



MOLTEN SULFUR – The darkest areas on Io may be flows of molten sulfur spewed from its active volcanoes. Other areas are probably surface deposits of salt mixtures, sulfur, and sublimate deposits from the volcanoes. Taken by Voyager 1 on March 5 from 377,000 km (234,000 mi).

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Pasadena, California

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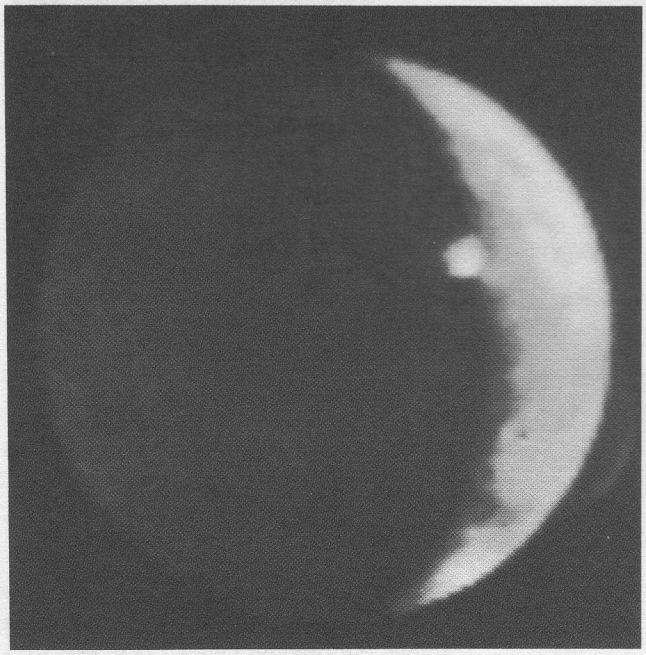
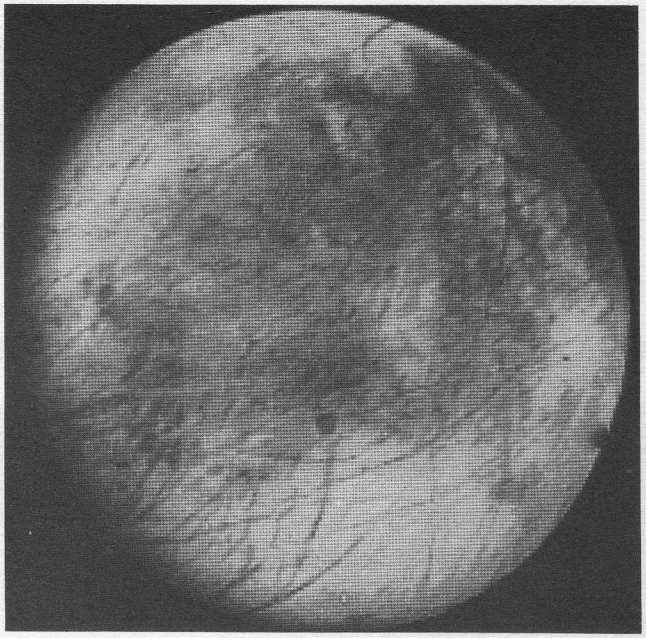
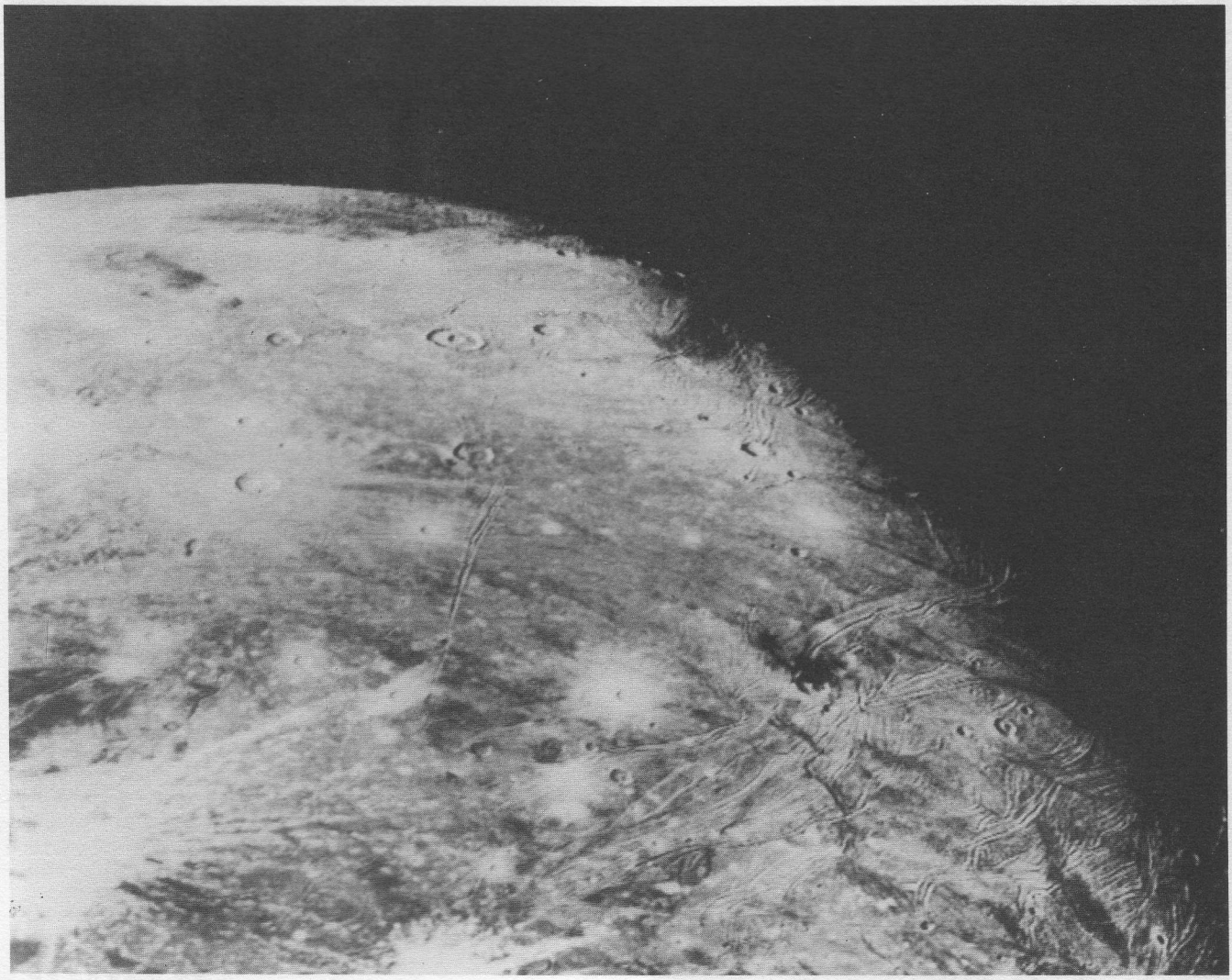
EXPLOSIVE MOON – An enormous volcanic explosion is silhouetted against dark space over Io's bright limb, throwing solid material as high as 160 km (100 mi). With an ejection velocity of about 1930 km (1200 mi) per hour, ejecta would reach the crest of the fountain in a matter of minutes. On Earth, water (steam) is the major gas driving volcanic explosions, but since Io is thought to be extremely dry, other gases must be active. Voyager 1 was about 490,000 km (304,000 mi) from Io when this image was acquired on March 4.



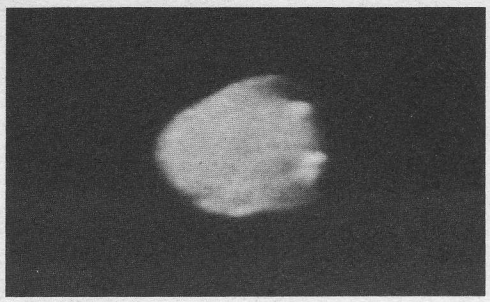
FIREWORKS – Simultaneous eruptions on Io shoot ash more than 260 (160 mi) into the sky. Two eruptions can be seen in this photo, one on the limb, the other on the terminator (the shadow between night and day). Forty times larger and 200 times more brilliant than Earth's full moon, Jupiter illuminates the dark hemisphere of Io. The photo was taken by Voyager 1 on March 8 while 4.5 million km (2.6 million mi) beyond the satellite. This is the photo in which Io's volcanoes were first discovered by JPL optical navigation engineer Linda A. Morabito.



EUROPA — One of the best images of Europa taken by Voyager 1 (from 2 million km) shows systems of long linear structures which criss-cross the surface in various directions. Possible faults or fractures, some of these features are over one thousand km long and about two to three hundred km wide. Voyager 2 is expected to get a closer look at the amber-colored satellite in July, 1979.

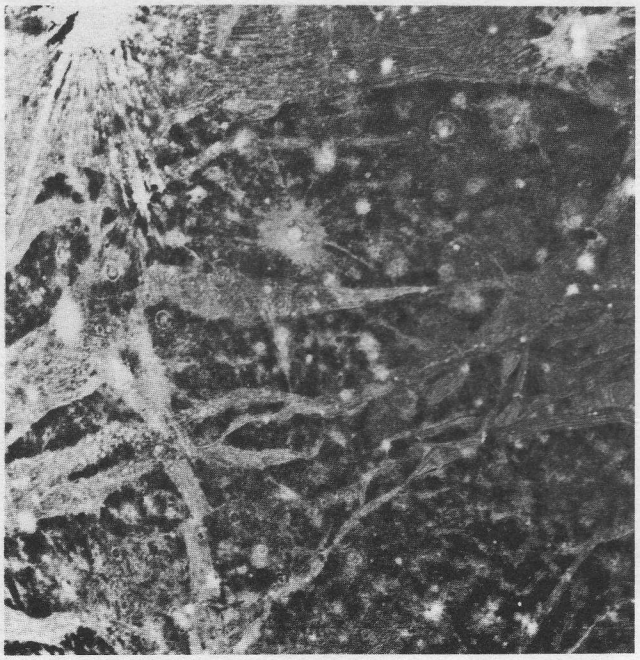


CALLISTO — This multi-ring basin (left center) on Callisto consists of a light floored central basin some 300 km (185 mi) in diameter surrounded by at least eight to ten discontinuous but rhythmically spaced ridges. The great number of rings observed around this basin is consistent with its low planetary density and probable low internal strength. These basins are thought to be formed by impacts. Voyager 1 took this photo on March 6 from about 200,000 km (125,000 mi).



PINPOINT OF LIGHT – Tiny, red Amalthea was discovered only 87 years ago. Too small ever to have been round, it has a long history of impact cratering and its red color may be a surface coating rather than a characteristic of the satellite's bulk. The innermost of Jupiter's 13 or 14 known satellites, it whizzes around the planet every 12 hours, only about 111,000 km (69,000 mi) from the cloud tops – outside the newly-discovered ring. Usually overpowered by the brilliance of Jupiter, Amalthea is especially hard to spot from Earth even with a large telescope. In this photo taken by Voyager 1 on March 4, Amalthea appears about 130 km (80 mi) high by 170 km (105 mi) wide.

GANYMEDE – Largest of Jupiter's satellites, Ganymede is about 1-1/2 times the size of our moon but only about half as dense. Therefore, it is probably composed of a mixture of rock and ice. Its features resemble mare and impact craters found on the moon, while the long white filaments resemble rays associated with impacts on the lunar surface. Voyager 1 took this photo on March 4 from a distance of 2.6 million km (1.6 million mi).



IMPACT CRATERS – Numerous impact craters pock the surface of Ganymede. Many of the craters have extensive bright ray systems; the older ones do not. Bright bands traversing the surface in various directions contain an intricate system of alternating linear bright and dark lines which may represent deformation of the crusted ice layer. These lines are particularly evident near the top of the picture. A bright band trending in a north-south direction in the lower left-hand portion of the picture is offset along a bright line, probably due to faulting. Two light circular areas in the right upper center of the picture may be the scars of ancient impact craters which have had their topographic expansion erased by flow of the crystal icy material. This photo was taken by Voyager 1 on March 5 from a range of 246,000 km (153,000 mi).

Voyager Bulletin

MISSION STATUS REPORT NO. 40 APRIL 13 , 1979

Mission Highlights

When Voyager 1 swings through the Saturn system in late 1980, the volume of information returned from its Jupiter Encounter will still be under study. Voyager 1 unmasked whole new worlds – presenting new puzzles. Space exploration, as one journalist noted, is an endless adventure.

By March 15, Voyager 1 had returned over 15,000 photographs of Jupiter and its moons. Add to this the wealth of data accumulated by 10 other science experiments, and it becomes apparent that it will require months, perhaps years, to wade through it all. Preliminary results are in, however.

The pictures provide immediate visual information. In 1965, Mariner 4 returned 22 frames of Mars, 200 by 200 elements, and each requiring 8-1/2 hours to play back to Earth at a data rate of 8-1/3 bits per second. Fourteen years later, at a data rate of 115,200 bits per second, Voyager 1 returned many of its 800 x 800 element pictures in about 48 seconds.

This issue will concentrate on Jupiter and its environs; subsequent issues will deal with the satellites.

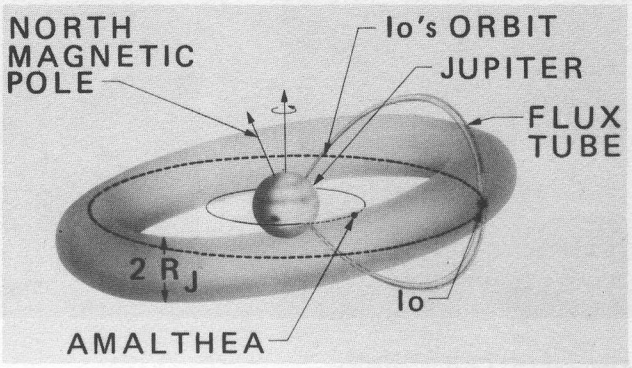
Sulfur Torus

Imagine a huge, glowing fluorescent tube, millions of miles in diameter. This is one model of the doughnut-shaped cloud (torus) of sulfur wobbling around Jupiter at the distance of Io's orbit.

Visible only in ultraviolet light, the torus of sulfur-three atoms (or doubly-ionized sulfur, which has lost two electrons per atom due to high temperatures), has a density of about 500 sulfur atoms per cubic centimeter (compared to less than 0.01 total particles per cubic centimeter in the interplanetary medium). Some sulfur was expected, but the density was a surprise.

In addition, a great deal of energy, perhaps as much as 500 billion watts of power, is required just to hold the particles in orbit. The sulfur was thought to be sputtered off the dry surface of Io, but that theory was laid to rest when Io's explosive volcanoes were discovered.

(contd)



SULFUR TORUS – Ultraviolet observations discovered a hot, charged ring of sulfur encircling Jupiter.

Update

Five weeks after its sweep through the Jovian system, Voyager 1 continues taking parting shots and scanning the system on the far side of the planet.

On April 9, Voyager 1 fired its attitude control thrusters to adjust its course toward Saturn, nearly 800 million kilometers (500 million miles) away. Nineteen months from now, in mid-November, 1980, Voyager 1 will get its closest look at the ringed planet and six of its companions.

Jupiter's orbital energy has already been used to accelerate the spacecraft to about 84,500 kilometers per hour (52,500 miles per hour) and altered its flight path. Without Jupiter's aid, Voyager 1 would require nearly 1.5 million kilograms (1600 tons) of fuel as opposed to 5 kilograms (11 pounds) to achieve the same flight path. Three more trajectory correction maneuvers are planned before Saturn Encounter.

Voyager 1 will now settle into a relatively quiet cruise mode, continuing to look at the dark side of Jupiter and its spectacular satellites, to sample the interplanetary medium, and to make regular instrument calibrations and tests.

Voyager 2's Jupiter observations begin on April 24, 76 days before its closest approach to the system on July 9. Now travelling with less than half Voyager 1's velocity, Voyager 2 is 64.6 million kilometers (40 million miles) from Jupiter. On April 16 through 20, the spacecraft will execute the sequence of events for July's Encounter. Voyager 1 made a similar dry run in December.

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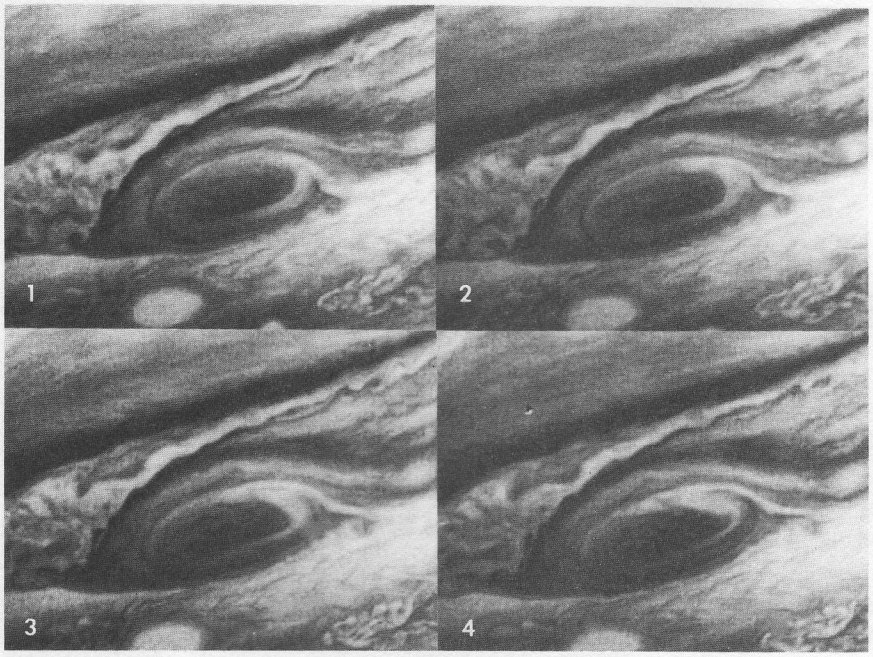


RED SPOT CIRCULATION – Taken one Jupiter rotation apart, these photos depict four days in the life of the centuries-old atmospheric feature. Changes in circulation during the 40-hour period are clearly visible, especially the flow of light material at the spot's right edge. The photos were taken on February 2-3, 1979 from 31 million km (19.4 million mi).

Atmospheric Characteristics

Jupiter is far more complex in its atmospheric motions than ever imagined. Linear flows diverge and vortices reverse direction. Neighboring jet streams flow in opposite directions. Its bright orange and white bands are in constant turmoil, yet appear to retain their sharp-edged structure down to resolutions of 25 kilometers. It looks at times like a dance between two unmixable fluids (like oil and water). Yet Jupiter's atmosphere is all gas, and material exchange between flows has been observed.

First sited from Earth nearly three centuries ago, the Great Red Spot remains a mystery. Is it a hurricane? Is it anchored to a feature deep below the cloud tops? Is it tied to a "floating raft" of solidified water in the lower levels of the atmosphere? Why has it existed for so long? Why is it reddish?

Variable in size and color, the spot today is about 21,000 by 11,000 km (13,000 by 7,000 mi) and paler than when the Pioneer spacecraft photographed it in 1973-74. It has remained at about the same position, 22 degrees south latitude, for as long as it has been observed. It is cold and bright and oscillates slightly as it migrates east and west every 90 days. Whirling counterclockwise, one complete trip takes about six days. High-speed jet streams flowing in opposite directions above and below it may explain its whirling motion.

The task remains to reconstruct the atmospheric flow patterns on the planet. One technique for this is to assemble hundreds of still photos to produce, in effect, a movie in which the motions are readily visible and easily mapped.

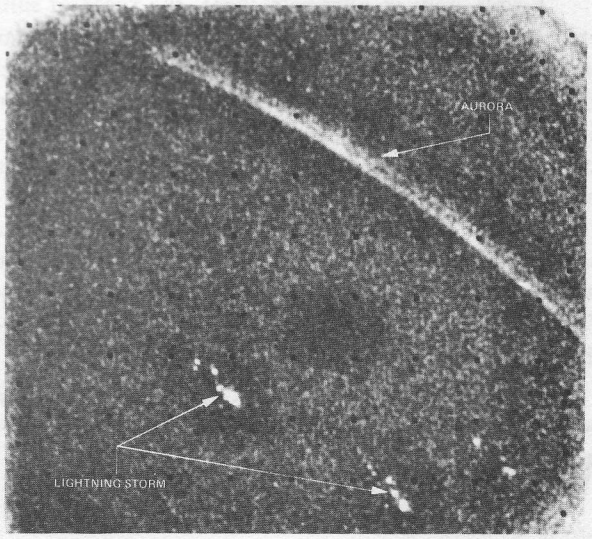
Northern Lights and Lightning

Earth and Jupiter have at least one thing in common – auroras. Voyager 1 spotted the largest aurora ever seen by mankind – nearly 29,000 kilometers (18,000 miles) long – at Jupiter's north pole. At Earth, auroras at the poles (northern and southern lights) are caused by the acceleration into the atmosphere of charged particles from the Van Allen radiation belts along the magnetic lines of force. Similar processes probably cause Jupiter's autoras.

First detected in the ultraviolet, Jupiter's auroras were much stronger than expected and detectable on both the night and day sides of the planet. Analysis of the auroras will aid in deciphering the planet's atmospheric composition, already known to consist primarily of hydrogen, with helium and some ammonia, methane, and water.

The long-exposure photograph of the aurora also appears to show a lightning storm – nineteen bright spots several thousand miles south of the aurora. Lightning had been suspected to exist on Jupiter, but at deeper levels of the atmosphere.

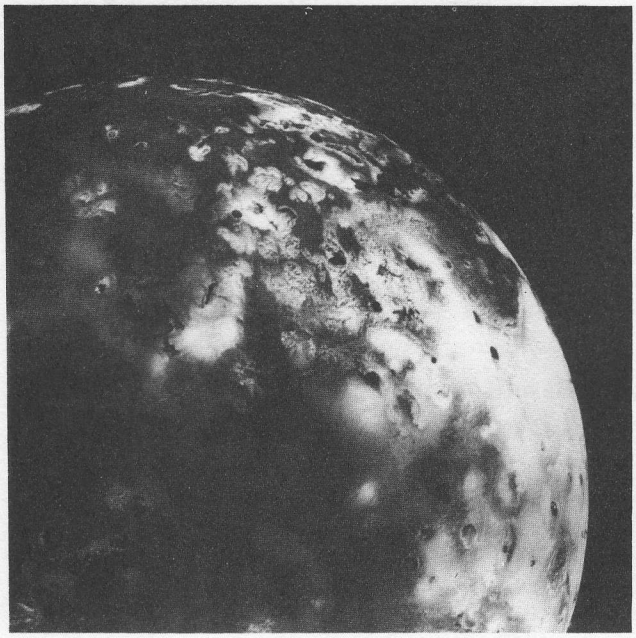
In a classic laboratory experiment, an electrical current (lightning) passed through a mixture of hydrogen, methane, ammonia, and water, has been shown to set off a reaction that forms more complex organic molecules. Whether such a process has occurred on Jupiter awaits further analysis.



"NORTHERN LIGHTS" – A long exposure (3 minutes, 12 seconds) captured this aurora and lightning storms on Jupiter's dark side six hours after closest approach on March 5, 1979.

Voyager Bulletin

MISSION STATUS REPORT NO. 41 APRIL 27, 1979



YOUNG SURFACE — Even before discovery of Io's active volcanoes, the lack of impact craters suggested that the surface is relatively young. The reddish, white and black areas are probably surface deposits, possibly consisting of mixtures of salts, sulfur and sublimate deposits. Many of the black spots are associated with craters, probably of volcanic origin. The smallest features visible are about 10 km (6 mi) across in this photo taken by Voyager 1 on March 5, 1979 at a range of 377,000 km (234,300 mi).

CLOSE LOOK AT Io — Io's equatorial region contains a myriad of complex features: mountains and plateaus bounded by scarps that vary from irregular to linear, vast smooth plains, rough bright areas. This image was acquired on March 5, 1979, at a range of 82,500 km (51,300 mi) and shows an area approximately 600 km (370 mi) square.

"There is no such thing as a boring Galilean satellite."
L. A. Soderblom
Deputy Team Leader, Imaging Team

Prior to the Pioneer spacecraft's observations in 1973-74, Jupiter's five innermost satellites, including the four largest, the Galileans, were mere pinpoints of light to man, indistinguishable except for their positions. By March 6, however all five had become unique, distinctive individuals.

Before Voyager, these satellites were as unknown as the planet Mars was in 1700. Voyager 1 scanned them at resolutions comparable to the Mariner observations of Mars in the early 1970's — in effect, 270 years of planetary exploration compressed into five days.

Amalthea

Tiny Amalthea, innermost of Jupiter's companions, had never been photographed with any spatial resolution. Weeks of Earth-based observations, combined with Voyager's optical navigation photos and computer calculations, were required to pinpoint its orbital path so that accurate pointing instructions could be given to the cameras.

Barely 140 km (90 mi) high by 260 km (160 mi) long, Amalthea always points its long axis toward Jupiter. Its elongated shape may suggest that it is on the verge of being broken apart by a tug of war between the gravities of Jupiter and the satellites.

Taken from a distance of about 421,000 km (262,000 mi) with a resolution of about 8 km (5 mi), photos of Amalthea confirmed its reddish coloring. Its reflectivity is very low, however, so that its surface composition is probably not ice, frost, or sulfur.

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Puzzling Io

Of all the satellites, Io generated the most excitement. As Voyager 1 closed in on Io, the puzzle was why its surface, so cratered and pocked when viewed from a distance, began to look smoother and younger as the spacecraft neared. Theories of erosion due to intense bombardment from Jupiter's radiation were advanced.

But the mystery was solved with the discovery of active volcanoes spewing sulfur 160 km (100 mi) high and showering it down on the crust, obliterating the old surface. Infrared data indicated hot spots at the locations of the plumes identified in the photographs, confirming the find.

Io's is undoubtedly the most active known surface in the solar system, surpassing even the Earth. If a spacecraft were to fly past Earth, it is unlikely that any volcanic activity would be visible despite the great number of volcanoes. But Io! As many as seven simultaneously erupting volcanoes have been identified.

Most of Io's volcanoes are extremely violent – similar to Vesuvius or Etna. Some evidence of Hawaiian-type volcanoes exists – vents through which the hot magma oozes rather than erupts. Infrared studies have observed lava lakes which may be as much as 400 degrees Fahrenheit warmer than the surrounding surface.

The source of Jupiter's hot sulfur torus is no longer a mystery. But the questions are now: What heats Io? Does the volcanic material come from the core or is it scraped from the underside of the continually overlaid crust? What is the propulsive gas forcing the material out through the volcanic vents, since Io's surface appears waterless?

One theory is that a tug of war between Jupiter and the other Galilean satellites has created gravitational tidal forces that have melted Io's core. Or, Io may have an extremely thin crust which is constantly being scraped away by the interior heat, shot out through the volcanic vents, redistributed on the surface, covered over by subsequent eruptions, and continually recycled in this way, with some ions and neutrals escaping into space to form the sulfur torus.

Voyager 2 will take a series of photos of Io over a 10-hour period to make a time-lapse sequence of the exploding volcanoes and their dynamics.

As Voyager 1 plunged under the south pole of Io, it was expected to pass through a highly-charged region known as the flux tube, where as much as 1 million amperes of electrical current travel along magnetic field lines connecting the satellite with the planet. Preliminary data indicate that Voyager 1 did not pass through the flux tube; the location of the tube had shifted from predictions.

Europa

Voyager 1 had only a distant look at Europa, the third satellite from the planet, but the photos are tantalizing and Voyager 2 will fly half a million miles closer to the amber-colored satellite, returning pictures at about the resolution of Voyager 1's Jupiter photos. Slightly smaller than Io, Europa is also a rocky body seemingly coated with ice and frost. Dark streaks 80 by 1900 to 2900 km (50 by 1200 to 1800 mi) may represent a system of large fractures or faults on the surface.

Summary

With one spacecraft 53 million km (33 million mi) beyond it and another approaching from 54 million km (34 million mi), Jupiter is well-surrounded by curious Voyagers from Earth.

Now 73 days from its closest approach to the planet, Voyager 2 has begun its Jovian observations which will reach a peak on July 9. Approaching on a different sunline than the first ship, the second spacecraft will augment the findings, rounding out the picture of the Jovian system. In addition, changes since Voyager 1's passage will be studied.

Voyager 2 is scanning the entire system in the ultraviolet, sampling Jupiter's radio emissions and interactions with the solar wind, and taking selected pictures.

Currently in a quiet cruise mode, Voyager 1 has passed the half-way mark on its journey from Earth to Saturn. The active program in the computer command subsystem aboard the craft is designed to nearly automate its activities during the next four months so that Voyager 1 needs minimal attention while Voyager 2 takes center stage.

More Results from Voyager 1

There is much for the second spacecraft to look forward to – another look at the ring, measurements of the extremely active solar wind, closer looks at some of the satellites, and different views of all, including the ever-changing face of Jupiter. And Voyager 2 will not be subjected to as severe a radiation hazard as was its sister ship, since it will fly further from the planet.

A Ringed Planet

Floating 35,000 miles above Jupiter's visible cloud tops, a wafer-thin ring of rocky particles poses a new problem. No longer is the question: Why are some planets (Saturn and Uranus) ringed? But: Why are the inner, terrestrial planets not ringed?

Bowshock

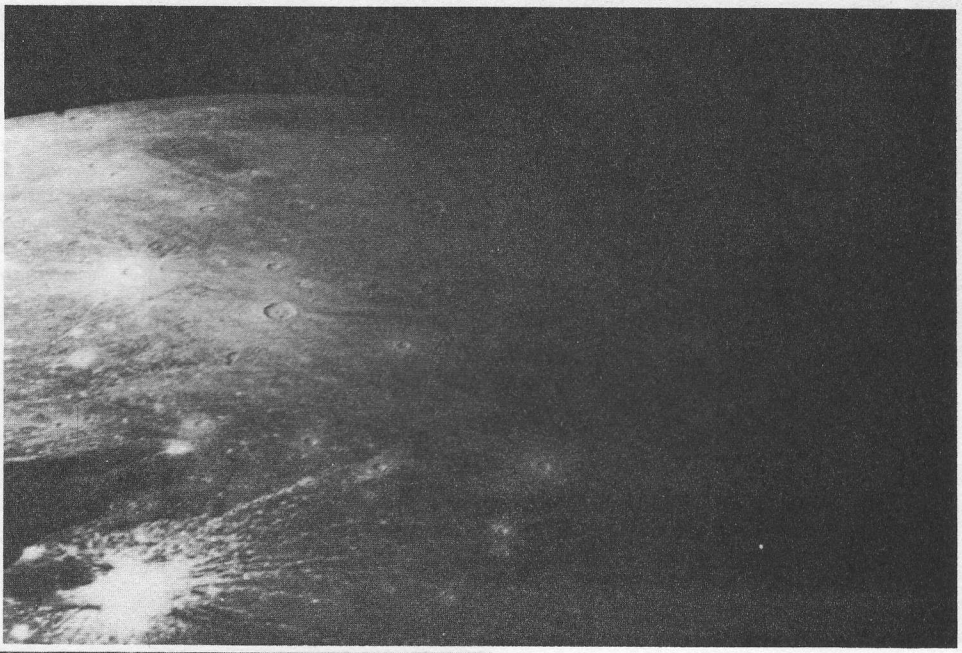
On its inbound leg, Voyager 1 recorded at least five crossings of the bowshock as Jupiter's magnetosphere expanded and receded under varying pressure from the solar wind. The bowshock is the line of interaction between the particles trapped by a planet's magnetic field and the particles in the solar wind. The first crossing was February 28, about 6 million kilometers (3.8 million miles) from the planet. The last crossing was at 3.6 million kilometers (2.1 million miles).

Radiation

Voyager 1 withstood 1000 times the lethal dose of radiation for humans as it passed between Jupiter and Io. As expected, several of the instruments were saturated, but recovered well once outside the danger zone.

Voyager Bulletin

MISSION STATUS REPORT NO. 42 MAY 11, 1979



IMPACTS – Numerous bright ray craters and odd, grooved structures pock the surface of Ganymede, Jupiter's largest satellite. The brightness of the craters, their ejected material, and the grooves may indicate the presence of younger, "cleaner" ice which has not yet been darkened by micrometeoride bombardment. The large, bright ray crater (south of top photo, north of bottom photo) has ejecta rays extending as far as 300 to 500 km (185 to 310 mi). These two photos, taken by Voyager 1 on March 5 from a range of 230 to 250 thousand km (143 to 155 thousand mi), have a resolution of about 4.5 km (2.8 mi) and may be mosaicked by fitting matching features together.

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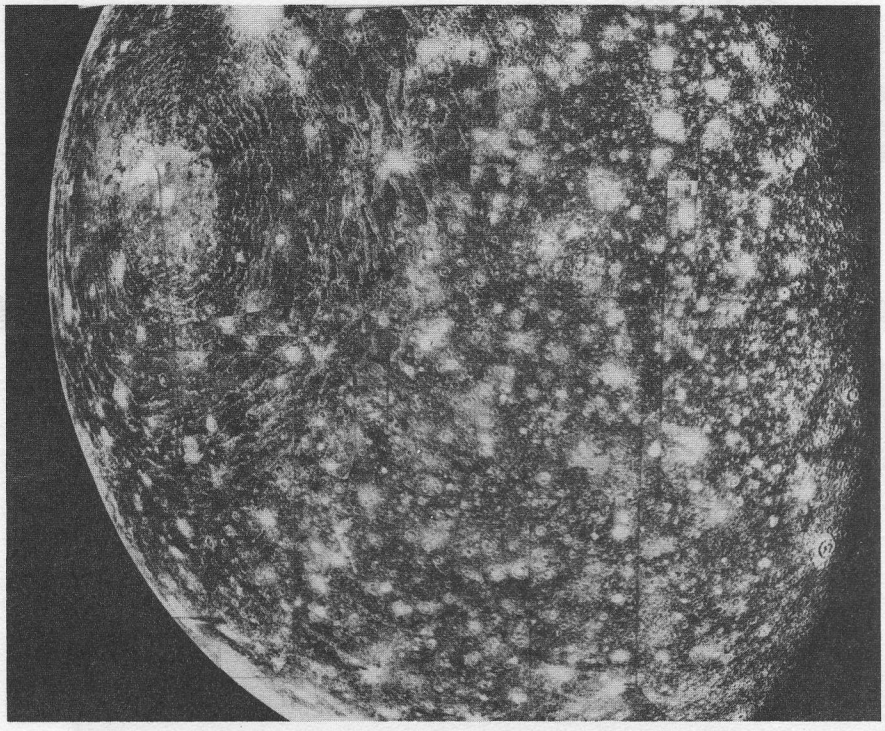
Voyager 2: Jupiter Minus 59 Days

Voyager 1: Saturn Minus 551 Days

Recorded Mission Status (213) 354-7237
Status Bulletin Editor (213) 354-4438
Public Information Office (213) 354-5011



QUICK FROZEN – Heavily-cratered Callisto is the outermost, darkest, and probably the oldest surface of Jupiter's Galilean satellites. While it is thought to have a muddy or rocky core with an icy crust, its surface is densely covered with impact craters ranging in size from 20 to 50 km (12 to 30 mi) in diameter, with very few larger ones. The lack of large craters indicates that Callisto lacks firm enough crustal foundations to support mountains or chasms, since ice sinks and flows under heavy loads. An exception to the small craters is the large impact basin (left) with numerous concentric rings rippling outward from its center. Extending more than 1000 km (620 mi) outward from the 600 km (370 mi) basin, the ripples probably were formed as the fragile, icy crust heaved under the impact of a large meteorite and then quickly froze again in the cold, airless environment.

B.V. (before Voyager), the two largest and outermost Galilean satellites, Ganymede and Callisto, were thought to be very similar. Both are larger than the planet Mercury. Both are relatively dark (but not as dark as Earth's moon), indicating a surface covered with dark rock rather than white ice. Both are very lightweight, however, having a density about twice that of water – inconsistent with a rocky composition.

There the similarities begin to end. Callisto has perhaps the most ancient surface of any of Jupiter's Galilean satellites. Its crust is cratered like that of Mercury, indicating little recent change. Countless impact craters mar its surface, probably the result of meteorite bombardment over the past four billion years. It is mountainless. The features are shallow – there are no sharp rims or deep canyons. Questions arise: Could it be that Callisto's crust is not strong enough to support geological relief? That mountains sink and canyons rise on a sea of slush?

One explanation is that Callisto has a muddy or rocky core, with an icy crust floating on a sea of warmer ice. At times, the warmer ice leaks out of the interior, freezing on the surface at temperatures more than 200 degrees below zero (Fahrenheit). Splattered meteorites and captured interplanetary dust coat the surface with dark debris, accounting for the darkness of the satellite.

Ganymede's surface may be only a quarter as ancient as its sister – perhaps only one billion years old – since its crust shows much more evidence of recent change. Its icy surface lacks the numbers of impact craters, and the existing ones are surrounded by bright rays of material tossed out by the impact of meteorites. The bright spots might be fresh ice, while the dark ones could be "dirt" gouged out of internal material.

But the intriguing features on Ganymede are the sinuous systems of ridges and grooves traversing the surface like so many tire tracks. Some of these cracks display offsets similar to shifts in streets and streams caused on Earth by crust movement or Earthquakes, implying that the same sort of processes exist on Ganymede. Some areas of the satellite appear to have piled-up crustal segments similar to ice jams at Earth's polar regions.

Crustal movements on Earth are caused by convection cells generated by heat from the core. There may have been, or perhaps still is, enough heat from radioactive elements within Ganymede to warm the mantle, create convective currents, and thus crack the icy crust.

Voyager 2 in Observatory Phase

Images of Jupiter now being obtained every two hours by Voyager 2 will be used to create a time-lapse movie sequence of the Great Red Spot. The movie will cover the period from April 24 to May 27, as the spacecraft zooms 21 million km (13 million mi) closer to the giant planet, and will show large-scale changes in the atmosphere since Voyager 1's visit.

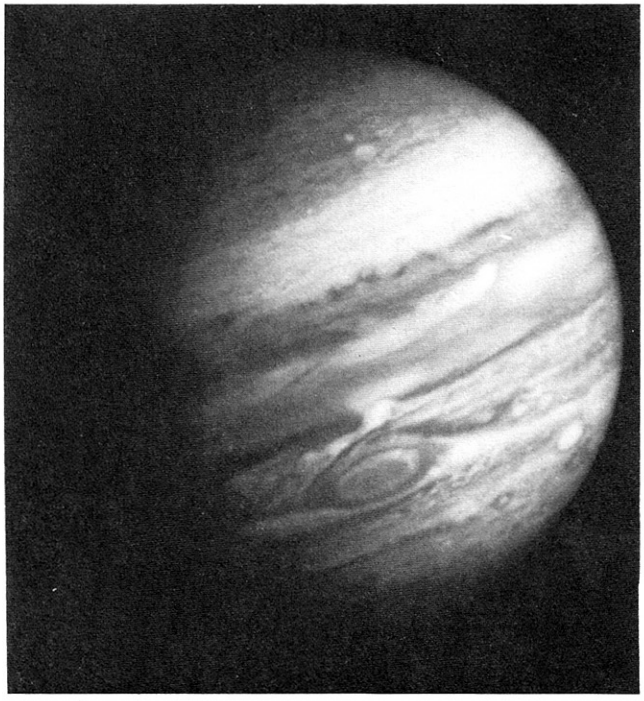
In addition to the imaging, Jovian-system scans in the ultraviolet and field and particle measurements of the solar wind near Jupiter comprise most of the spacecraft's daily routine thoughout May. Calibrations of other instruments and measurements of the radio emissions are also performed regularly.

A trajectory correction maneuver is planned for May 25 to adjust the spacecraft's aiming point, and a fourth maneuver is planned in late June just 12 days before closest approach to the planet.

Voyager Bulletin

MISSION STATUS REPORT NO. 43 JUNE 5, 1979

VOYAGER 1
January 24, 1979
40 million km (25 million mi)



VOYAGER 2
May 9, 1979
46 million km (29 million mi)

Jupiter is sporting quite a different face than it did just four months ago, as these photos by the two Voyager spacecraft clearly show. Although individual features in the Jovian atmosphere are long-lived, the winds blow at greatly different speeds at various latitudes, causing the clouds to move independently of each other and to change longitudes.

Important changes appear in the region of the Great Red Spot: One of the white ovals has drifted from a position southwest of the Great Red Spot in late January to its present position 60 degrees eastward. Its movement has allowed another feature to move in behind it, from a January position just west of the white oval to a May position directly beneath the GRS. The white oval is drifting east at a rate of about 0.35 degree a day (1.57 miles per hour), while the GRS itself is drifting west at about 0.26 degree a day (1.48 miles per hour).

The bright "tongue" extending upward from the red spot is interacting with a thin, bright cloud above it that has traveled twice around Jupiter in four months. Turbulent wave patterns to the west of the GRS, which have been observed since 1975, appear to be breaking up. This area has undergone three major periods of activity in the last 15 years.

The Voyager 2 photo shows a dark spot which has developed along the northern edge of the dark equatorial region. A similar feature was observed by Pioneer 10 in December, 1973. Dark spots in the northern latitudes in the Voyager 1 photo are still present. These spots are thought to be holes in the upper cloud decks penetrating into the warmer lower cloud layers.

Ganymede is visible at the lower left of the Voyager 1 photo.

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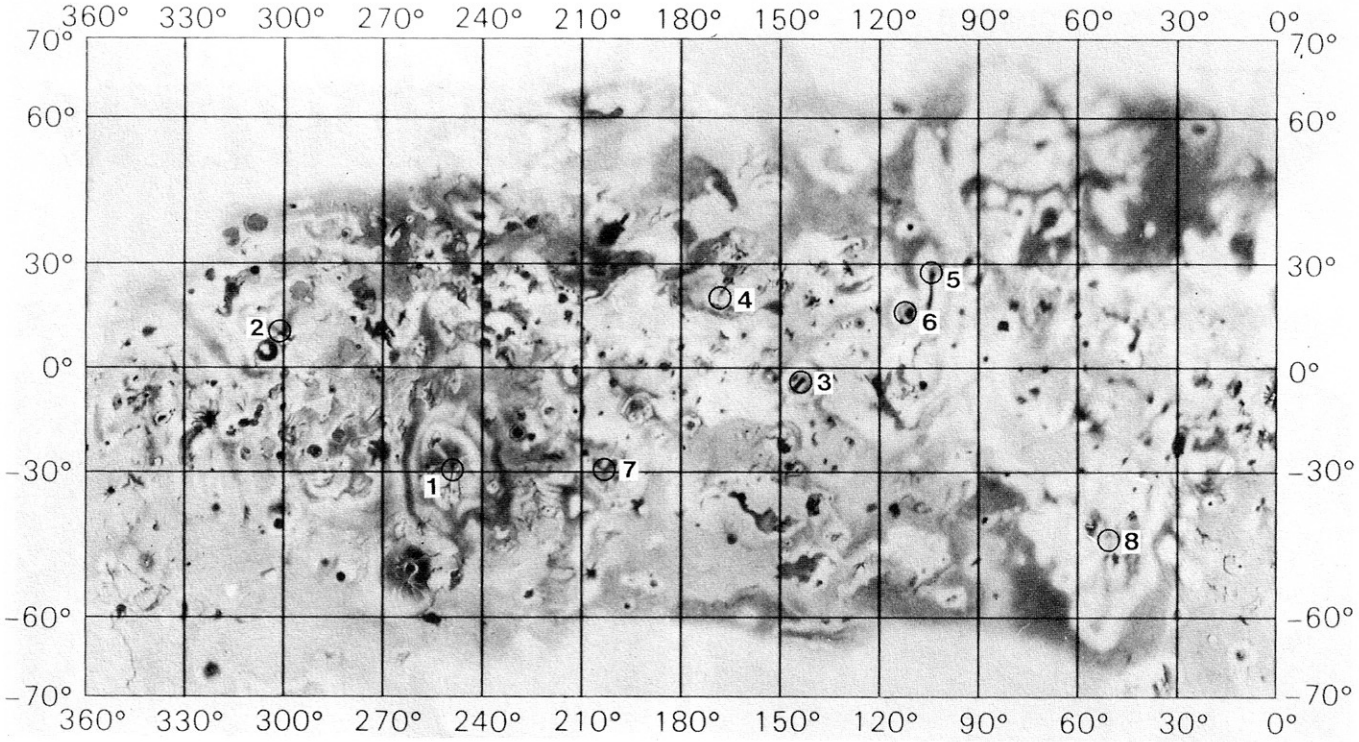
VOYAGER 2: JUPITER MINUS 34 DAYS
VOYAGER 1: SATURN MINUS 525 DAYS

Recorded Mission Status (213) 354-7237
Status Bulletin Editor (213) 354-4438
Public Information Office (213) 354-5011



MERCATOR PROJECTIONS — Preliminary shaded relief maps of the Galilean satellites have been prepared from images taken during Voyager 1's flight through the Jovian system. The scale here is 1:100 million (1 cm = 1000 km). Io shows a complex system of calderas, flows, and volcanic features. Featureless, smooth plains lie between the volcanic regions. The plumes of eight active volcanoes identified to date are indicated by arrows.

Mission Highlights

Thirty-four days from its closest approach to Jupiter, Voyager 2 is operating smoothly with only a few special concerns. Heating in one section of the buss (the spacecraft's main body) causes frequency drifts in the ship's remaining radio receiver (the primary receiver and a tracking loop capacitor on the remaining receiver failed in April, 1978). The frequency drifts limit routine commanding. Such heating occurs primarily when the spacecraft is maneuvered off the sun line (as in special tests or calibrations, or maneuvers) or when the spacecraft power consumption changes. Events likely to cause temperature increases have been identified and plans for commanding during these periods have been revised.

Final target selection for the imaging, ultraviolet, and infrared experiments has been completed and the computer sequences are being finished to be relayed to the spacecraft before the near encounter period (July 8-9). Some planned observations have had to be simplified due to the space occupied in the processor by the backup mission load (BML). The BML is designed to automatically operate the spacecraft (although at a reduced activity level) through a Saturn encounter in August, 1981 should the remaining receiver fail. In that event, the spacecraft would not be able to receive radio signals from Earth, but could still transmit data to Earth.)

The photopolarimeter instrument will not operate the polarization wheel due to sticking problems similar to those on Voyager 1's instrument. Near ultraviolet photometry of Jupiter and Ganymede will be obtained, however, as well as a multi-color study of Io's ion torus.

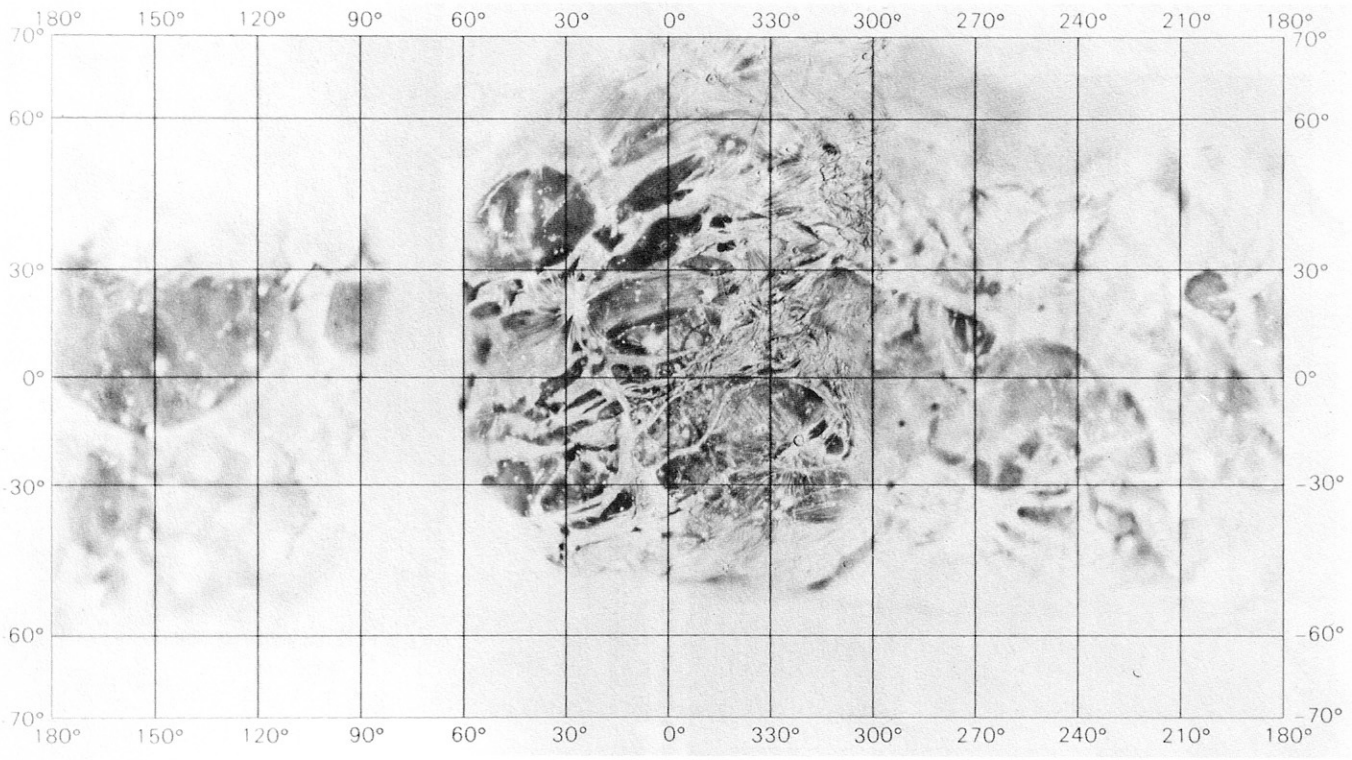
The infrared interferometer spectrometer and radiometer (IRIS) is in a long heating cycle scheduled to end about June 20. The heating was required to preserve instrument performance due to degradation of a bonding material in the motor. The degradation could cause the mirror alignments to be off just fractions of a wavelength of light, but even 0.001 cm (0.00005 in.) would be enough to affect the quality of the data.

Imaging

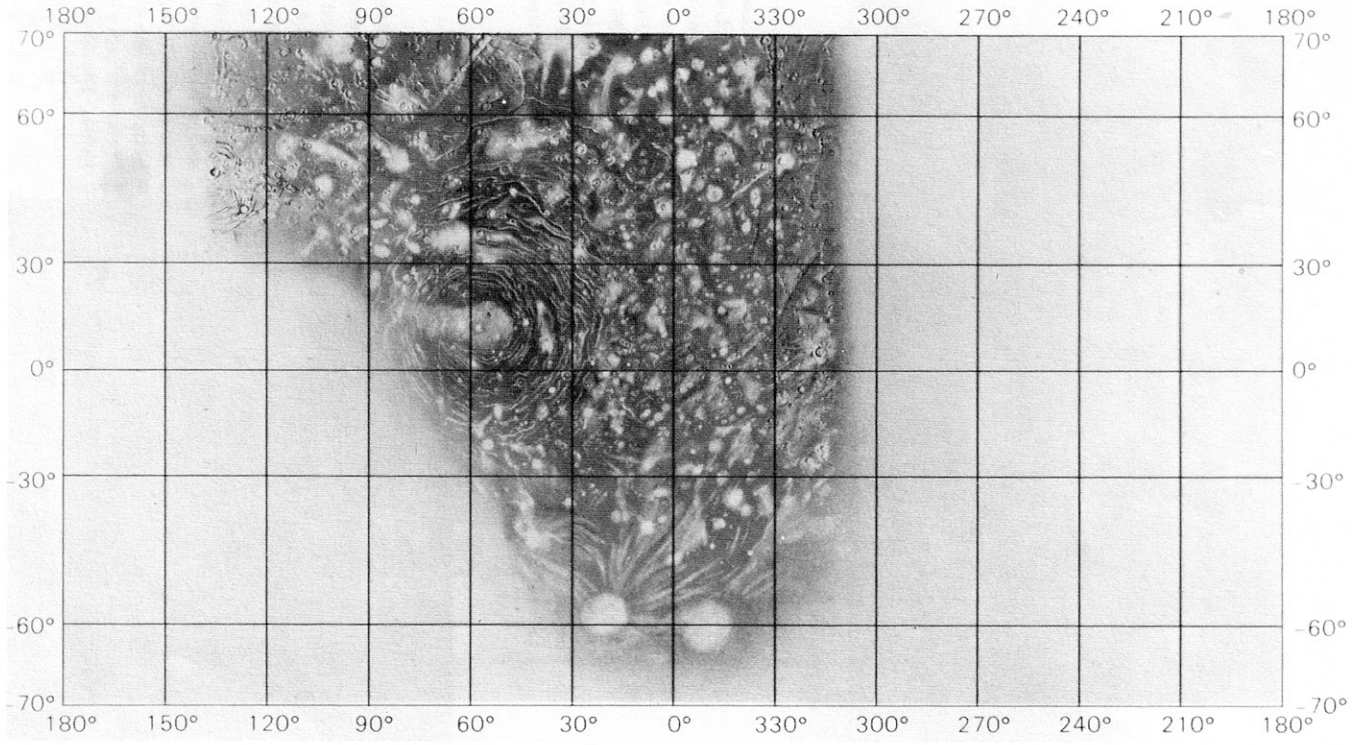
Voyager 2 is now mosaicking the disk of Jupiter, taking a set of 12 narrow angle and 2 wide angle frames once an hour to ensure full coverage of the planet.

An "approach zoom" movie showing changes at the Great Red Spot since Voyager 1's flyby is now being assembled from images taken during the past four weeks as the spacecraft "zoomed" closer to the planet.

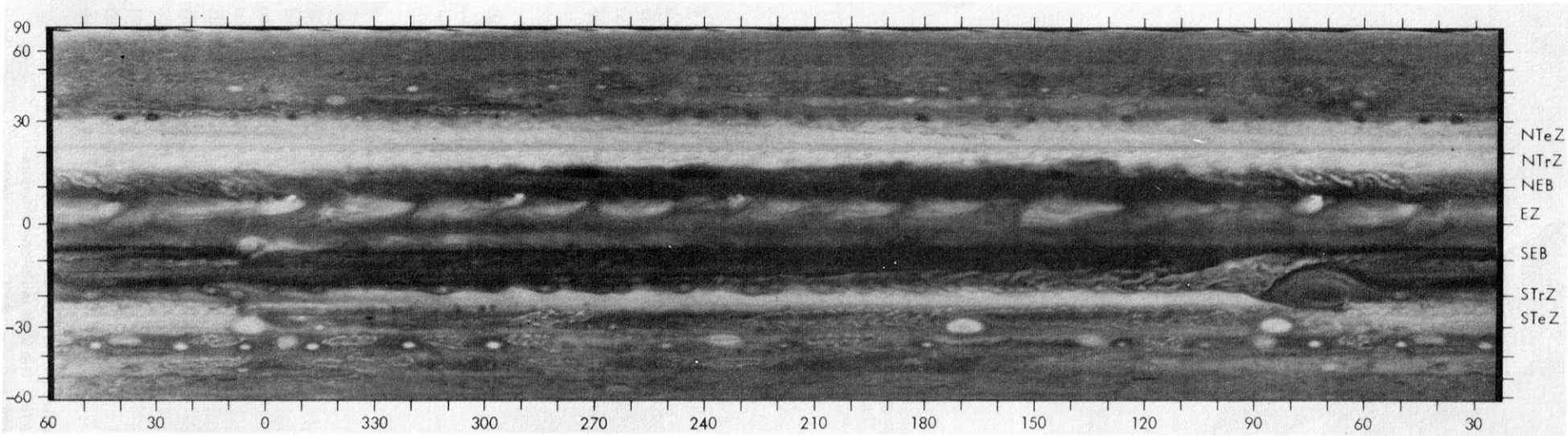
Fifty hours of nearly continuous picture-taking from May 27 to May 29 covered five rotations of Jupiter and will supplement Voyager 1's color movie of ten rotations made last January. The ultraviolet spectrometer experiment will also use the frames to search for auroral activity on the planet.



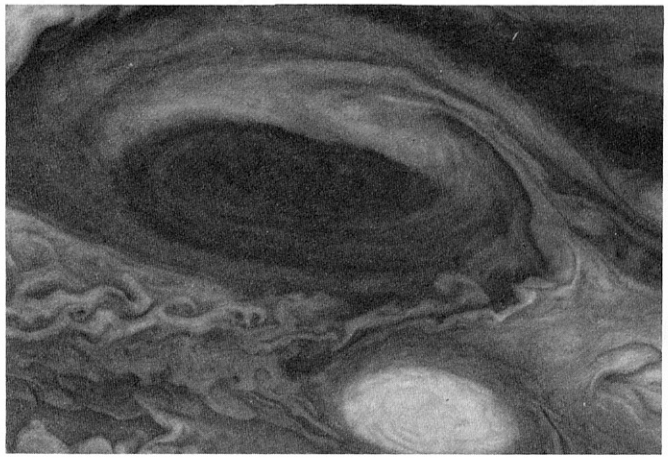
GANYMEDE — An older, cratered terrain is criss-crossed by a younger system of grooves which divide Ganymede's surface into features as large as 1000 km across. The grooves may have resulted from faulting or surface expansion, while the absence of larger craters or mountains on Ganymede suggests an icy crust which collapses under the weight of heavier features.



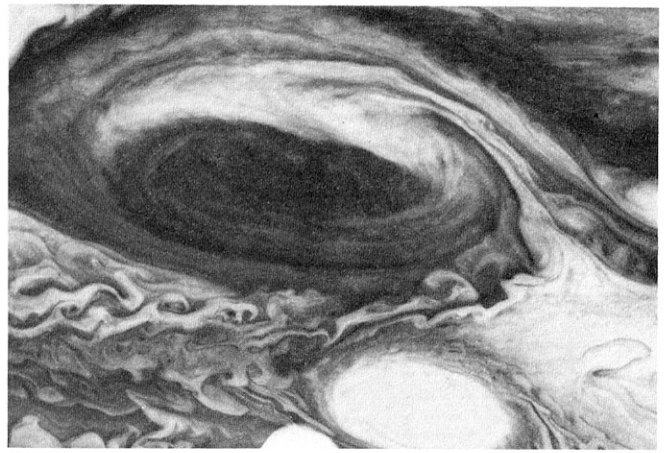
CALLISTO — More heavily cratered than the other Galileans, Callisto has no grooved terrain as does Ganymede, suggesting that their crusts have evolved very differently. The large multi-ring structure centered at about +10° latitude, 60° longitude, has no central basin, ring mountains, or radial ejecta.



CYLINDRICAL JUPITER — This computer-generated map was made from 10 color images of Jupiter taken February 1, 1979, by Voyager 1, during a single, 10-hour rotation of the planet. Computers at the Jet Propulsion Laboratory's Image Processing Lab then turned the photos into this cylindrical projection. Such a projection is invaluable as an instantaneous view of the entire planet. Along the northern edge of the north equatorial belt (NEB) are four dark-brown, oblong regions believed by some scientists to be openings in the more colorful upper cloud decks, allowing the darker clouds beneath to be seen. The broad equatorial zone (EZ) is dominated by a series of plumes, possibly regions of intense convective activity, encircling the entire planet. In the southern hemisphere the Great Red Spot is located at about 75 degrees longitude. South of the Great Red Spot in the south temperate zone (STeZ) three large white ovals, seen from Earth-based observatories for the past few decades, are located at 5 degrees, 85 degrees and 170 degrees longitude. Resolution in this map is 375 miles (600 kilometers). Since Jupiter's atmospheric features drift around the planet, longitude is based on the orientation of the planet's magnetic field. Symbols at right edge of photo denote major atmospheric features (dark belts and light zones): NTeZ — north temperature zone; NTrZ — north tropical zone; NEB — north equatorial belt; EZ — equatorial zone; SEB — south equatorial belt; STrZ — south tropical zone; and STeZ — south temperate zone.



COLOR ENHANCEMENT — Voyager's color photographs are actually composites of at least three exposures taken through different filters. The photo at left shows "normal" color, while the photo at right has been "color-enhanced" emphasizing red and blue to make some features stand out. Some bizarre and beautiful pictures result from color enhancement techniques. In this view, the Great Red Spot and a white oval with a wake of counter-rotating vortices extend about 24,000 km (15,000 mi) from the top to the bottom of the frame. Puffy features inside the GRS and "reverse-S" spirals inside both the GRS and white oval are visible. The Great Red Spot appears to be one of the coldest areas on the planet, while the white ovals are also cold.



Voyager Bulletin

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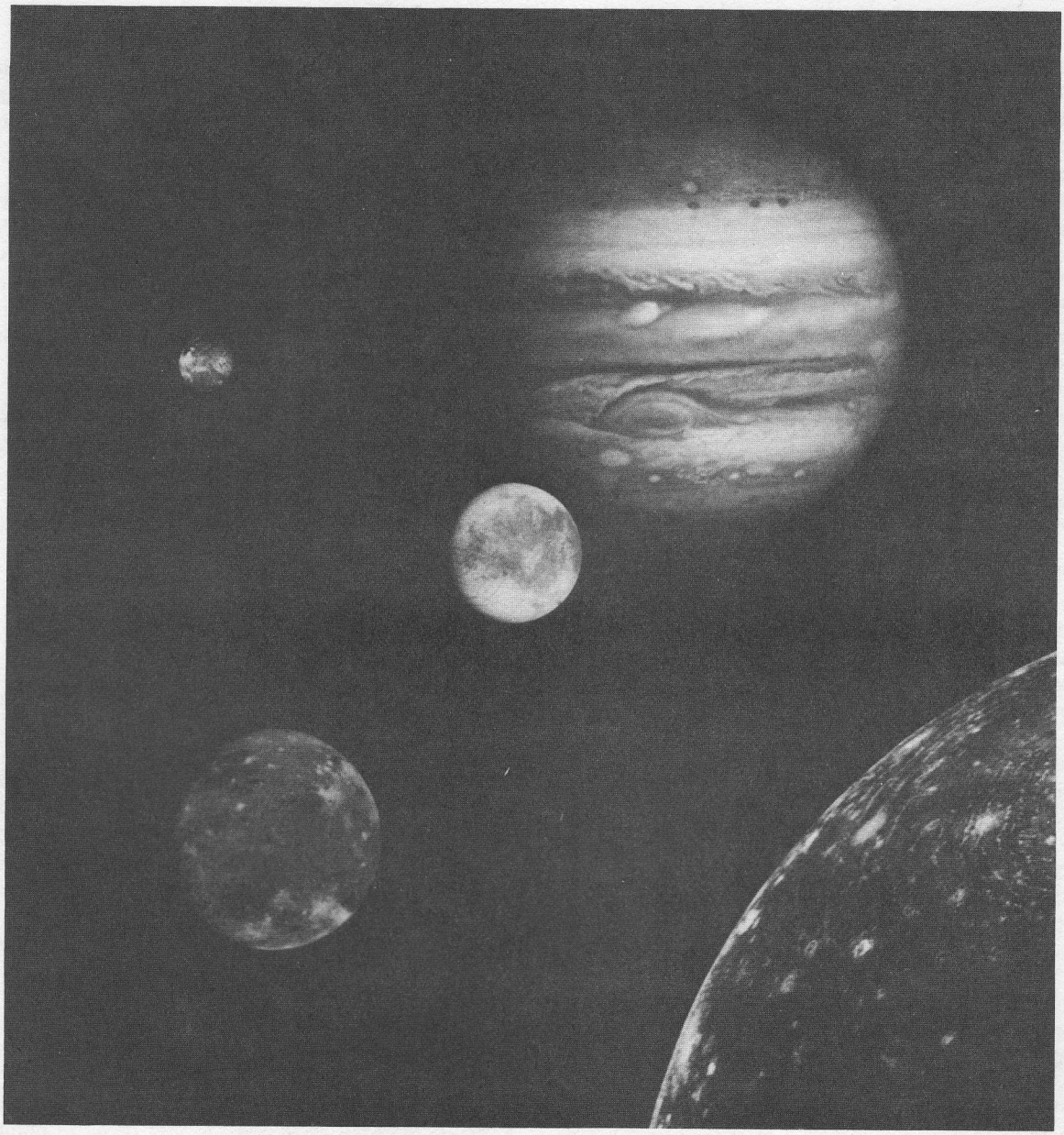

MINIATURE SOLAR SYSTEM — An artist's montage of Jupiter and its four largest satellites, the Galileans, shows the bodies in their relative positions, although not to scale with respect to Jupiter. Startling new discoveries by Voyager 1 have resulted in additions to Voyager 2's mission design, including observations of a faint particle ring encircling Jupiter and a time-lapse sequence of Io and its eight active volcanoes. Voyager 2 will see opposite faces of the satellites than seen in March by Voyager 1, first encountering the outermost Galilean, Callisto, (lower right) then Ganymede, Europa (center), Amalthea (not shown), Jupiter, and lastly Io (left).

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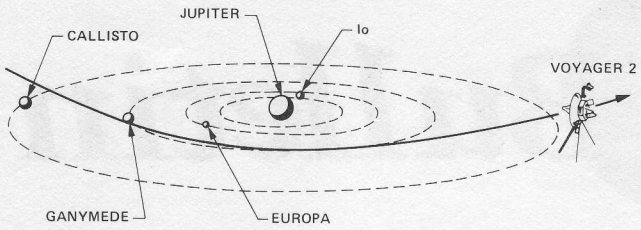
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Voyager 2: Jupiter Minus 10 Days

Recorded Mission Status (213) 354-7237
Status Bulletin Editor (213) 354-4438
Public Information Office (213) 354-5011



Voyager 2's Swing through the Jovian System – July 8-10, 1979.

Voyager 2 Highlights

For the last nine weeks, Voyager 2 has been following much the same routine as Voyager 1 did during its inbound flight to Jupiter: daily imaging of Jupiter converting to mosaicking as the planet's diameter grew too large to be captured in a single narrow-angle frame; daily scans of the satellite system in the ultraviolet; periodic tests and calibrations; infrared composition searches; and monitoring of the interplanetary medium surrounding the spacecraft.

Voyager 2's close encounters will be distinctly different, however. The second craft will make its closest approaches to Callisto, Ganymede, Europa, and Amalthea before encountering Jupiter, unlike the first Voyager which encountered all of the satellites after Jupiter closest approach.

Voyager 2 will make its Jupiter pass deep in the southern hemisphere, unlike Voyager 1 which flew by just south of the equator.

The two trajectories are unique and were designed for specific observations at both Jupiter and Saturn. Since Voyager 2 could be destined for a Uranus flyby in 1986, it has been targeted to fly further from Jupiter and its intense radiation than did Voyager 1. For this reason, Voyager 1 will not have a close flyby of Io.

Several highlights of the Voyager 2 near encounter include:

– High-resolution pictures of Europa, about ten times better than the March photos. Voyager 1 showed Europa to be laced with huge, intersecting linear features, even from a range of nearly 2 million kilometers.

– Ring observations, crossing the ring plane twice and making observations before and during each crossing. An attempt will be made to obtain a color picture of the thin ring of particles circling Jupiter.

– An Io "volcano watch", ten-hours of intensive imaging of Io to possibly provide a brief time-lapse history of erupting volcanoes on the satellite. The eruptions will probably not be evident as the pictures are received from the spacecraft but will require processing and color reconstruction.

Voyager 2 Operations

A final tweaking of Voyager 2's flight path before encounter was accomplished on June 27. The next trajectory correction, shortly after closest approach to Jupiter on July 9, will use the planet's gravity to slingshot the spacecraft towards Saturn.

After a two-month-long heat soak designed to retard further degradation of bonding material in the infrared interferometer spectrometer (IRIS), the instrument was turned on June 21 and is operating as planned. On the approach to the Jovian system, IRIS is measuring temperature differences in specific satellites as they disappear into Jupiter's shadow and then reappear into sunlight. IRIS is also measuring the energy budgets of specific satellites.

On June 24, the spacecraft was maneuvered off the earth line to allow ultraviolet observations across Io's orbit to measure vertical space above and below the satellite system.

The fields and particles instruments – the magnetometers, and plasma, low-energy charged particle, and cosmic ray detectors – continue to monitor interplanetary space and are detecting Jupiter's presence.

The spacecraft is expected to cross the bowshock for the first time about July 5, about 4.5 million kilometers from the planet. The bowshock is the line at which the supersonic stream of particles from the sun (the solar wind) meets the subsonic particles trapped by the planet's gravity field. Voyager 1 crossed the bowshock five times as the solar pressure varied.

The planetary radio astronomy and plasma wave experiments are also receiving strong indications of Jupiter's effect on its environs.

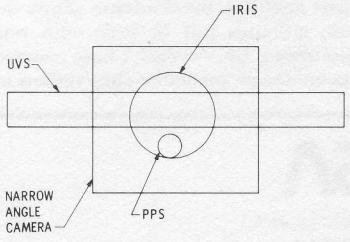
Photometry of Io and Europa this weekend will characterize and map the sodium distribution.

Summary

Ten days before its closest approach to Jupiter, Voyager 2 is 9.5 million km (5.9 million mi) from the giant planet, travelling with a heliocentric velocity of 9.9 km a second (22 thousand miles an hour). The pull of Jupiter's gravity will steadily accelerate it until it surpasses 27 km a second (60 thousand miles an hour) soon after closest approach to the planet. The effect of Jupiter's gravity will curve the spacecraft's trajectory, enabling its course to be set toward Saturn.

Radio signals now require about 51 minutes to travel one way between Earth and Voyager 2.

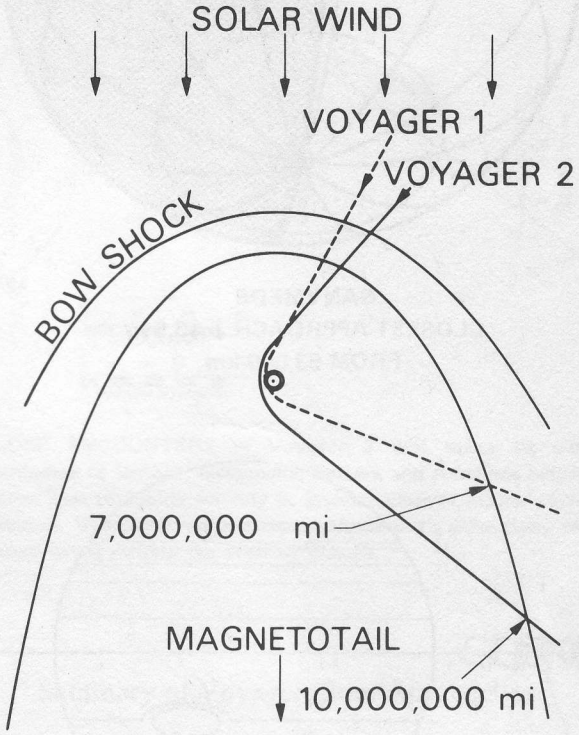
The lead ship, Voyager 1, is now about 113 million km (70 million mi) beyond Jupiter, travelling with a heliocentric velocity of about 23 km a second (51 thousand miles per hour) since its boost by Jupiter's gravity. Radio signals between earth and the ship travel 54 minutes.



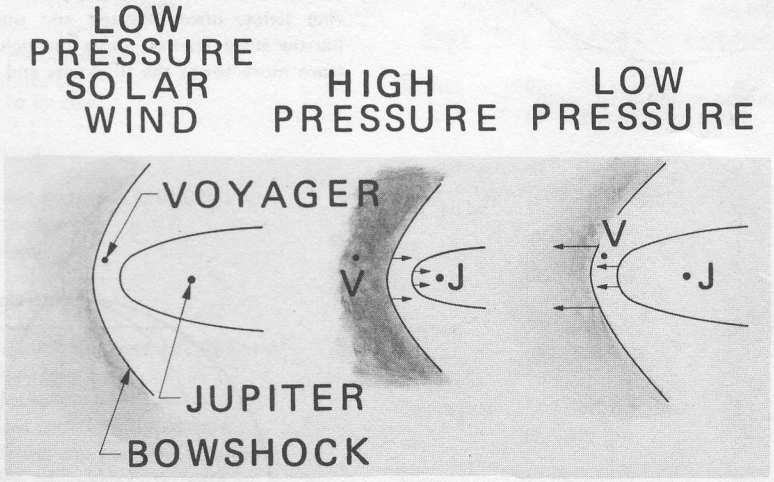
FIELDS OF VIEW – The fields of view of the optical instruments on Voyager 2's scan platform overlap so their data can be correlated.

Voyager Bulletin

MISSION STATUS REPORT NO. 45 JULY 5, 1979



MAGNETOTAIL PASSAGE — Voyager 2 will spend a longer period taking measurements in Jupiter's magnetosphere, perhaps as long as 30 days, in comparison to nearly 13 days for Voyager 1. On its outbound journey, Voyager 2 may cross the magnetopause as far as 10 million miles from Jupiter.



BOW SHOCK CROSSINGS — Voyager 2's first crossing of Jupiter's bow shock came July 2 at a distance of about 7 million km (4.4 million mi) from the planet. At least eleven crossings have been noted by the plasma instrument, magnetometers, and plasma wave instrument as of noon on July 5, as the solar pressure ebbed and flowed, sometimes causing the bow shock to overtake the spacecraft again. The bow shock is a surface separating the essentially undisturbed supersonic solar wind from the deflected subsonic solar wind outside the magnetosphere where particles are trapped by the planet's magnetic field.

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Recorded Mission Status (213) 354-7237
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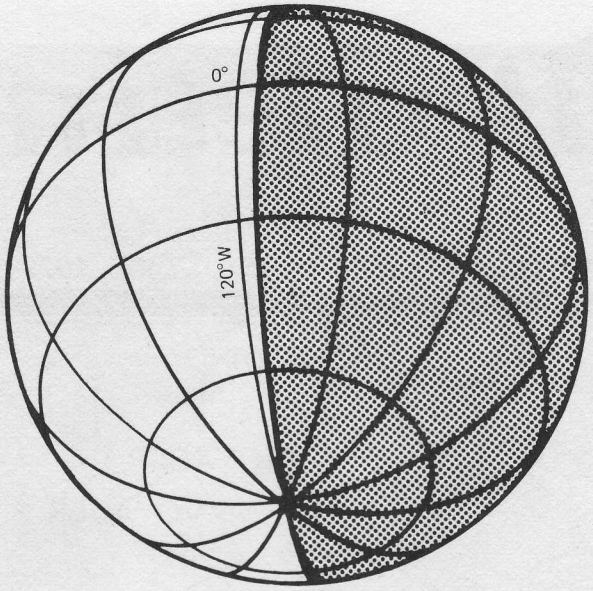
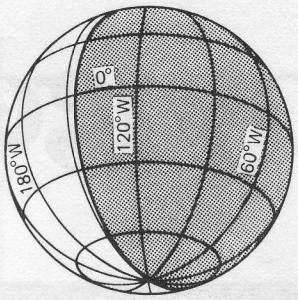
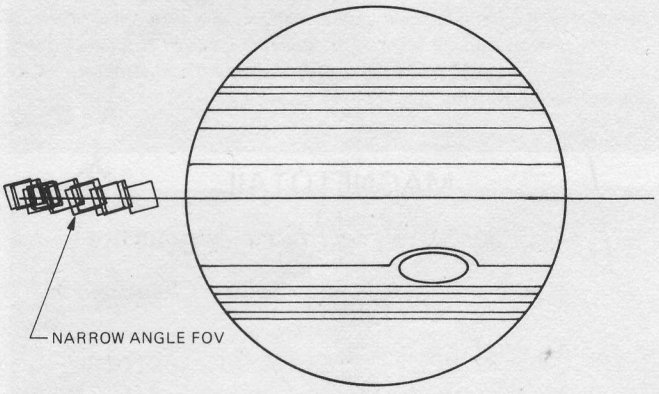


GANYMEDE
CLOSEST APPROACH J-15.5 hr
FROM 63,000 km



EUROPA
CLOSEST APPROACH J-4.5 hr
FROM 207,000 km

OPPOSITE FACES – These computer-generated plots show Voyager 2's view of Europa and Ganymede at the times of closest approach. Flying over 500 thousand kilometers closer to Europa than Voyager 1 did, Voyager 2 will learn more about the linear features seen on the Moon-sized satellite in March.

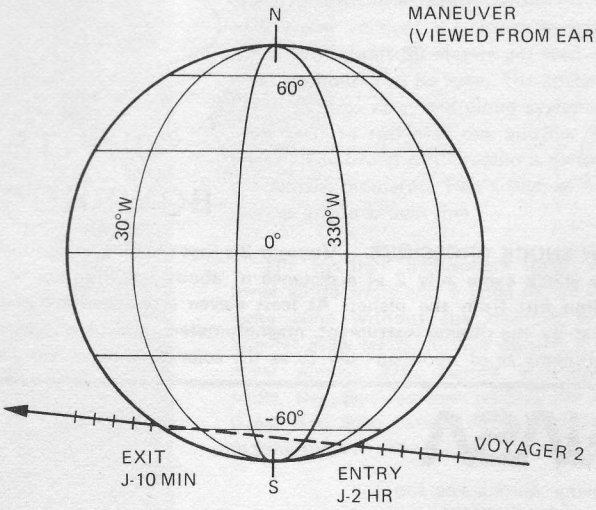


INBOUND RING PLANE CROSSING
JULY 8 5:03 pm PDT

RING CROSSING – Voyager 2 will cross the plane of Jupiter's thin ring twice, once inbound and once outbound. Both wide- and narrow-angle frames, some through color filters, will be taken to learn more about the thickness and composition.

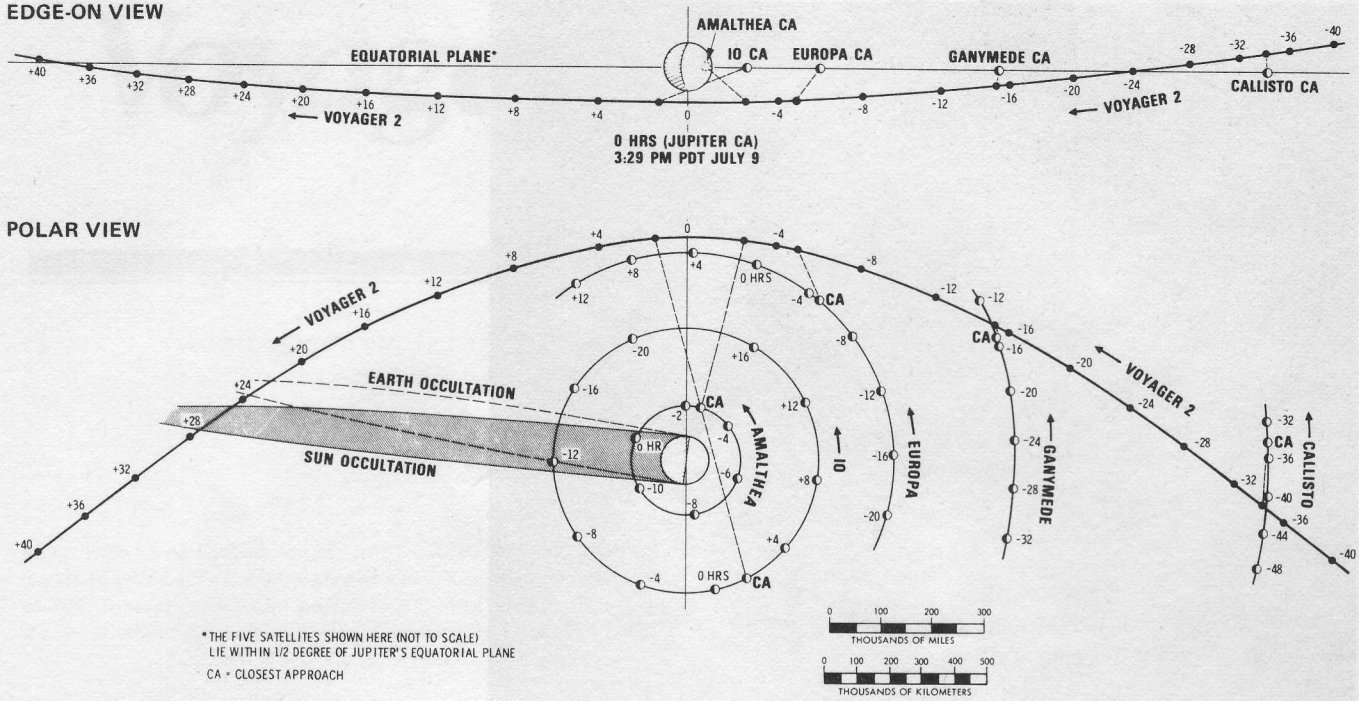
RADIO OCCULTATION – Voyager 2 will pass nearer the south pole of Jupiter, in contrast to Voyager 1's nearly equatorial pass. Only three hours after Jupiter closest approach in March, Voyager 1 moved into the planet's shadow, all radio signals blocked by the planet for nearly two hours. All data during this period, including the closest approach to Io, had to be tape recorded for later playback. Voyager 2 will enter earth occultation nearly 22 hours after its closest approach to Jupiter.

RADIO SCIENCE
EARTH OCCULTATION
MANEUVER
(VIEWED FROM EARTH)



TICKS ARE AT 10-MIN INTERVALS

VOYAGER 2 FLYBY OF JUPITER July 7-11, 1979



Sampling of Voyager 2 Encounter Activities

(Continuous observations by radio science, magnetometers, low-energy charged particle, plasma, and cosmic ray investigations, as well as mapping by imaging cameras, photopolarimeter, ultraviolet and infrared spectrometers.)

(All times are earth-received event start times, Pacific Daylight Time)

June 25	First targeted Callisto images
June 30	First targeted Ganymede images
July 2-3	Expected bowshock crossing
July 3	First targeted Europa images
July 7	First Callisto mosaic First targeted Io images
July 8	
2:39 a to 2:51 a	Ring observations
6:13 a	Callisto – closest approach (214,886 km)
7:32 a	Final Callisto mosaic
5:04 p to 5:29 p	Ring observations
5:32 p	First Ganymede mosaic
July 9	
1:06 a	Ganymede – closest approach (62,297 km)
1:12 a	Final Ganymede mosaic
10:02 a	Final Europa mosaic
11:45 a	Europa – closest approach (205,848 km)
1:53 p	Amalthea – closest approach (558,565 km)
4:21 p	Jupiter – closest approach (721,750 km)
4:34 p	Begin 10-hour Io "volcano watch"
5:09 p	Io – closest approach (1,129,850 km)
July 10	
2:30 a	Conclude Io "volcano watch"
2:21 p to 4:08 p	Earth occultation
5:10 p to 7:48 p	Sun occultation
6:48 p to 7:11 p	Ring observations
July 11	
8:43 a to 9:27 a	Ring observations

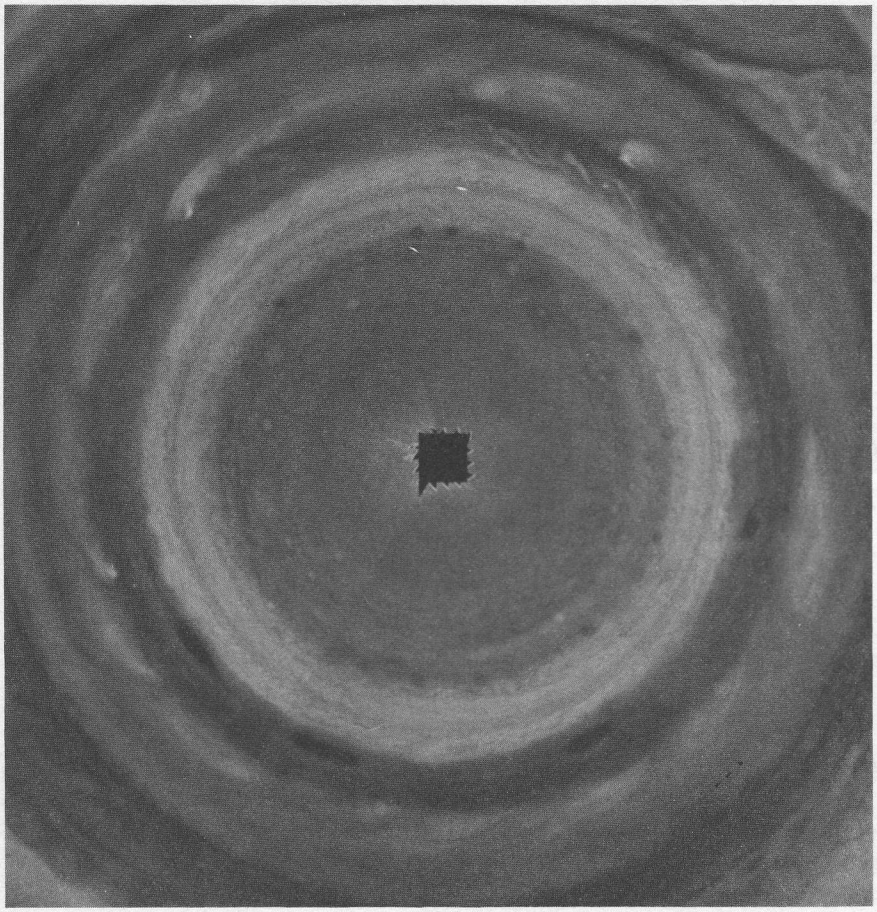
CLOSE ENCOUNTERS – Voyager 2 will make its closest approaches to Callisto, Ganymede, Europa, and Amalthea before its nearest pass to Jupiter on July 9. Steering clear of Jupiter's intense radiation, Voyager 2 will not repeat Voyager 1's close flyby of Io, instead flying outside the orbit of Europa.

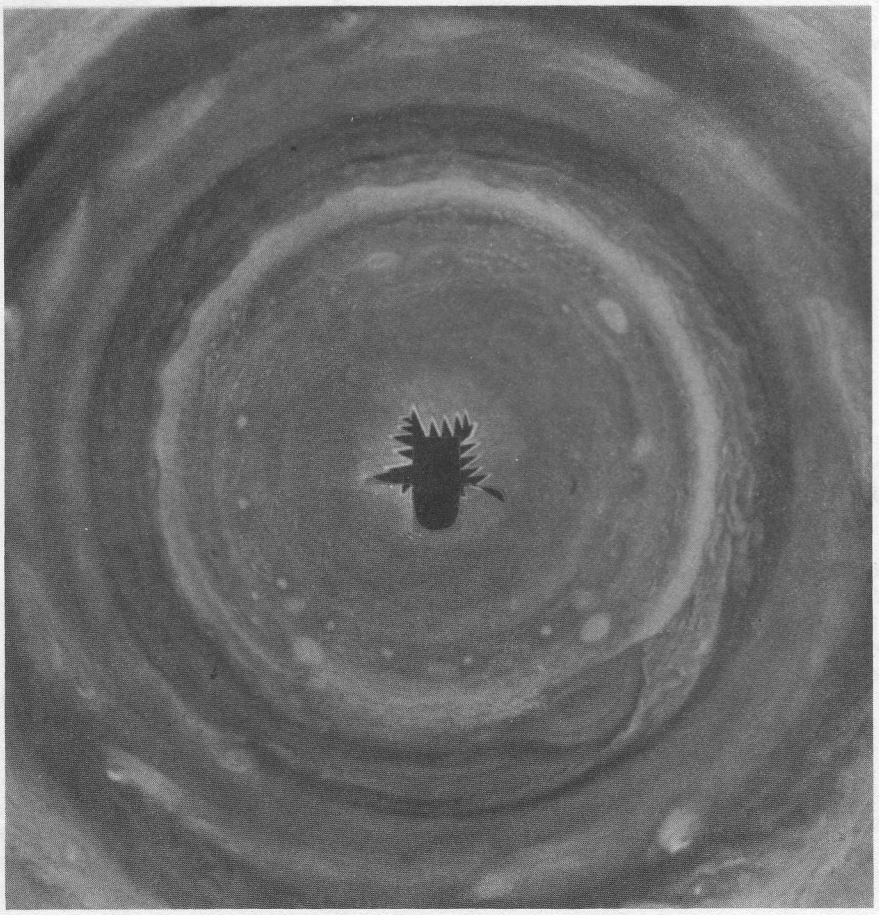
Summary of Voyager Close Approaches

	Voyager 1		Voyager 2
Body	Distance	Best Imaging Resolution (km)	Distance
Jupiter	280,000 km (174,000 mi)	6	721,750 km (448,470 mi)
Amalthea	417,100 km (259,173 mi)	7.8	558,600 km (347,100 mi)
Io	20,500 km (12,738 mi)	1*	1,129,850 km (702,056 mi)
Europa	733,800 km (454,962 mi)	33**	205,850 km (127,900 mi)
Ganymede	114,600 km (71,209 mi)	2	62,300 km (38,700 mi)
Callisto	126,100 km (78,355 mi)	2.3	214,900 km (136,500 mi)

*Best Io resolution was limited by image smear due to timing offset caused by radiation levels, not distance of closest approach.

**Final Europa images were obtained at a range of 18 million km, well before closest approach to the satellite.





POLAR PROJECTIONS—Jupiter's northern and southern hemispheres as they might be seen from directly above the poles are shown in these polar stereographic projections constructed by JPL's Image Processing Lab from Voyager 1 photos. The resolution is 600 kilometers (375 miles). The dark objects in the centers are areas where no pictures were available at that resolution.

In the northern hemisphere, the northward extent of the belt-zone structure is clearly shown to at least 50 degrees north latitude. At the northern edge of the equatorial region, the plumes are evenly spaced around the planet. Positions of the active cloud plumes, marked by bright nuclei, are not symmetrical. At about 32 degrees north, dark cloud vortices that move in westerly currents at about 30 meters per second (67 miles an hour) can be seen. The spacings of those features vary, and cloud systems have been seen to roll over one another in the region. The broad white region is divided by the North Temperate Belt's high-speed jet, seen as a thin brown line.

The southern hemisphere image shows three white ovals and a large region of the same zone without any discrete feature. Smaller scale spots, almost equally spaced, cover almost 270 degrees of longitude, while the disturbances trailing from the Great Red Spot extend about 180 degrees in longitude.

Voyager Bulletin

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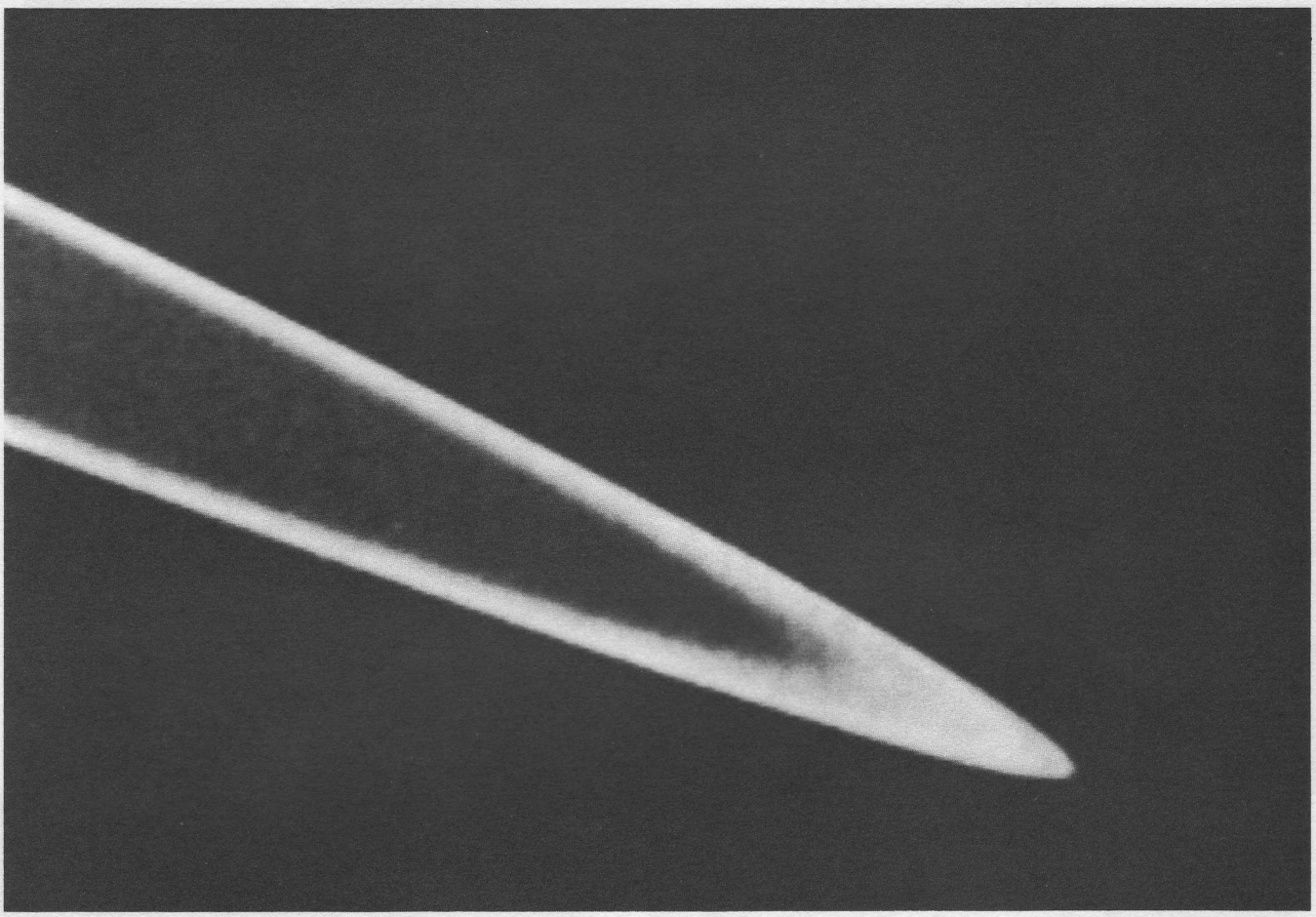

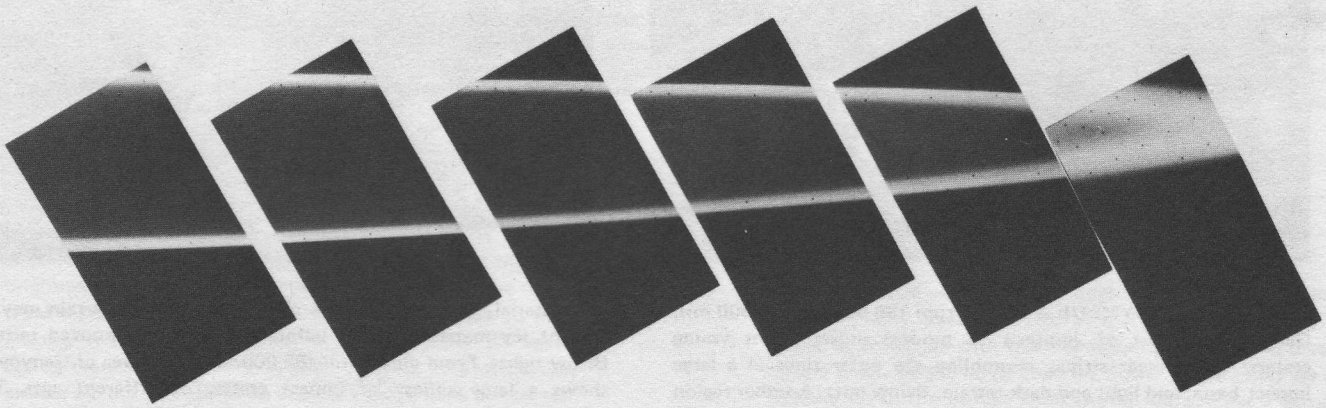

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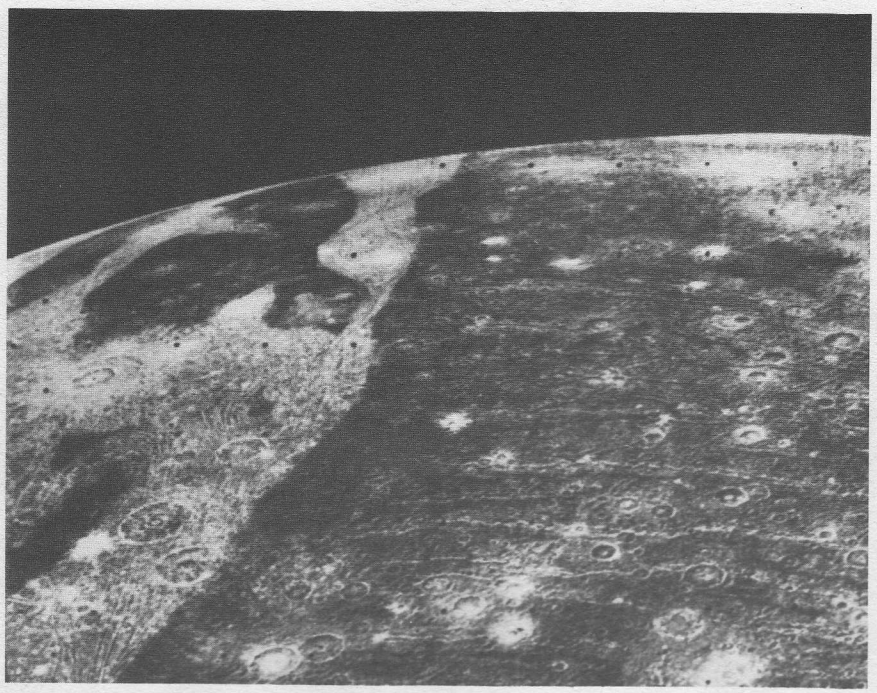
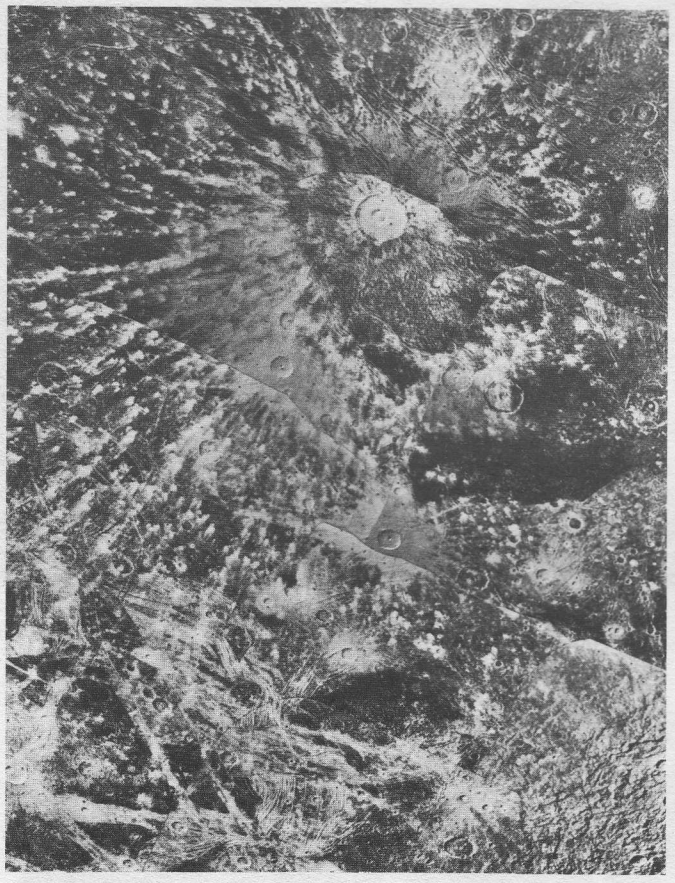
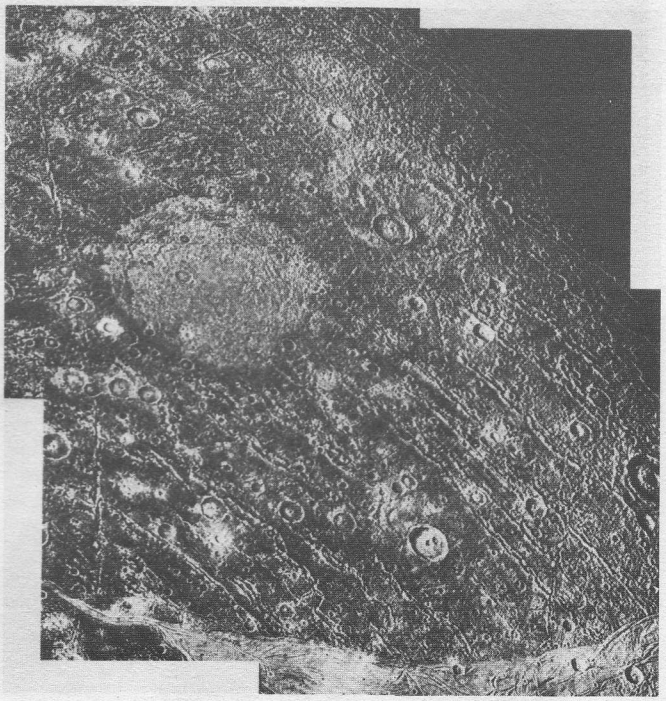
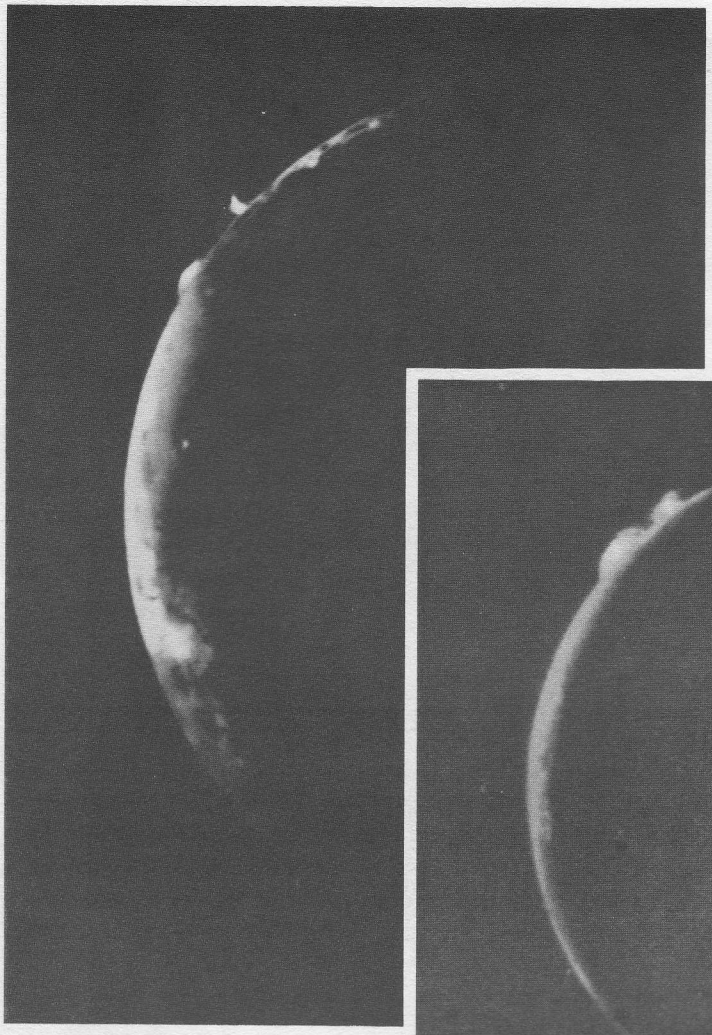
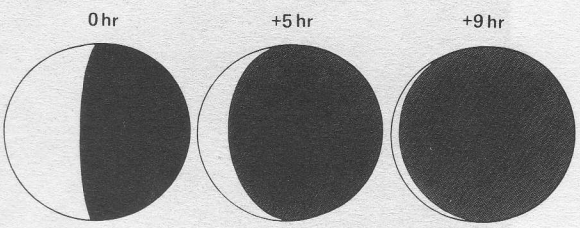


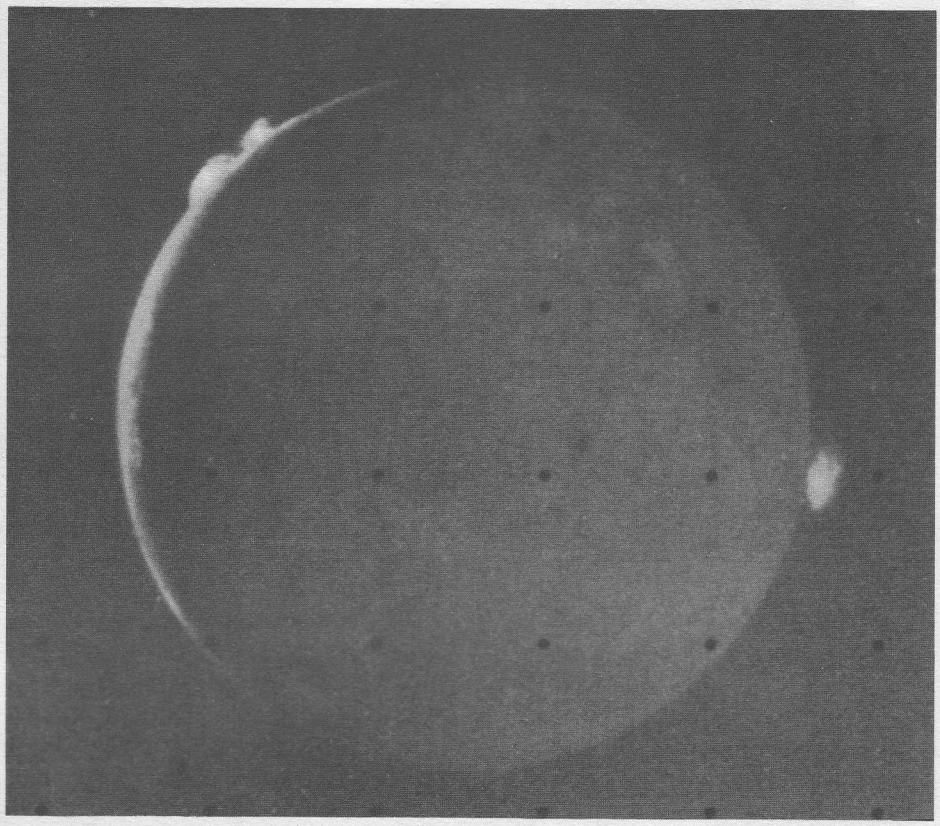




CRATERED GANYMEDE – TOP: From 138,000 km (86,000 mi), Ganymede, largest of Jupiter's 13 moons, shows bright young craters; light, linear stripes resembling the outer rings of a large impact basin; and light and dark terrain. Below left: Another region of Ganymede, observed on July 9 from about 100,000 km (62,000 mi), shows numerous impact craters, many with bright ray systems. The large ray crater at upper center is about 150 km (93 miles) in diameter. The rough mountainous terrain at lower right is the outer portion of a large fresh impact basin which was formed later than most of the other terrain. At the bottom of the mosaic, portions of grooved terrain transect older portions, possibly the result of newer icy material. The dark patches of heavily cratered terrain may be ancient icy material formed before the overlying grooved terrain. Below right: From closer still (85,000 km), this area of Ganymede shows a large variety of impact craters of different ages. The brightest craters are the youngest; the ejecta blankets from meteor impacts fade with age. In the center of this mosaic is a bright patch representing rebounding of the floor of the crater. The dirty ice has lost all topography except for faint circular patterns. Curved troughs and ridges marking an ancient enormous impact basin resemble features on Callisto. The basin itself has been destroyed by later geologic processes; only the ring features remain.







LIT PLUMES — Two of Io's active volcanoes (P5 and P6) are highlighted on the satellite's bright limb, spewing materials to a height of about 100 km (62 mi). This photo is one of about 200 which will be used to generate a time-lapse movie of Io's volcanic activity. The photos were taken on July 9 during a ten-hour period just after closest approach to Jupiter, at a range from Io of about 1 million km. The sunlit crescent of Io grew progressively slimmer with advancing night as Voyager 2 moved around to the satellite's dark side.

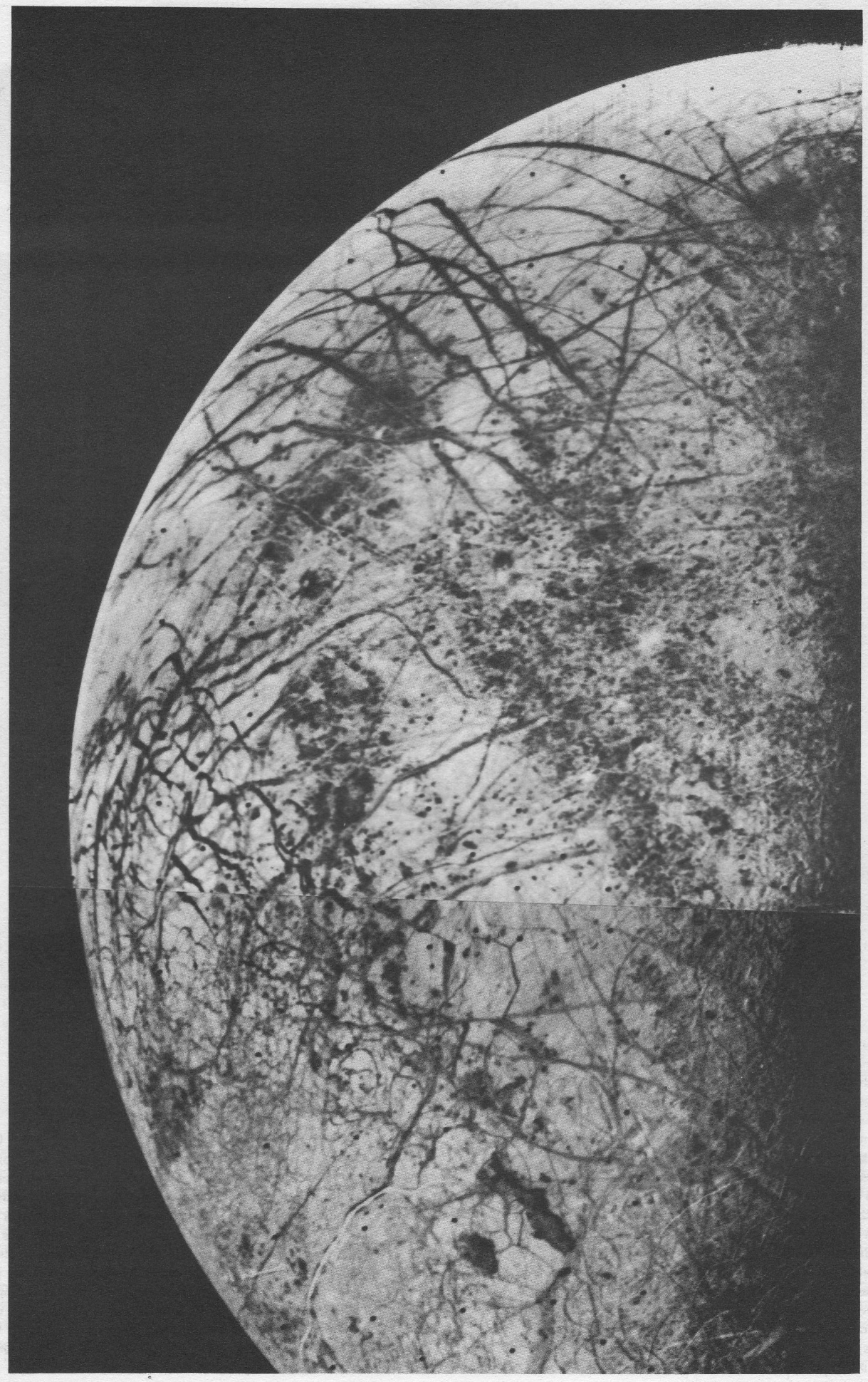
EXPLOSIVE Io — Of eight active volcanoes sighted in Voyager 1's pictures of Io last March, Voyager 2 had an opportunity to sight seven of them. Of the seven seen by Voyager 2, six are still active, and three are seen here on the limb of the satellite. On the bright limb at left, illuminated by sunlight, are Plume 5 (upper) and Plume 6 (lower), each about 100 km (62 mi) high. On the darker limb at right, illuminated by Jupiter, is Plume 2, about 185 km (115 mi) high and 325 km (200 mi) wide. Plume 2 is about one-and-one-half times larger than it was when it was discovered last March. The first and largest volcano discovered on Io, Plume 1, was not active.

FRONT PAGE:

BRIGHTLY RINGED — Even the people who reprogrammed Voyager 2 to show them clearer pictures of the ring discovered by Voyager 1 last March were surprised at the ring's brightness. The unexpected brightness is probably due to forward scattering of sunlight by small ring particles. In these photos, taken on July 10 about 26 hours after the spacecraft's closest approach to Jupiter, a fainter ring which may extend all the way down to Jupiter's cloud tops can be seen within the inner edge of the brighter outside ring. The outer ring appears to be about 6500 km (4000 mi) wide; Voyager 1 had caught the ring edge-on, leaving scientists unclear at that time as to the ring's structure. Taken on the dark side of Jupiter when Voyager 2 was about 1.5 million km (963,000 mi) from the planet and about 2° below the ring plane, some of the long exposures were blurred by spacecraft motion, especially in the extreme right frame in the lower photo.

BACK PAGE:

CRACKED ICE — Europa, the brightest of Jupiter's Galilean satellites, may have a surface of a thin ice crust overlying water or softer ice with fracture systems appearing as breaks in the crust. Bright linear features (lower center) may be ice welling up to the surface from within. Europa has a density about three times that of water, suggesting it has a large quantity of water. Very few impact craters are visible on the surface, suggesting a continual resurfacing process, perhaps by the production of fresh ice or snow along the cracks, and cold glacier-like flows. Both pictures were taken by Voyager 2 on July 9; the slight offset at the mosaicked edges (center) is due to slight differences in the angles and ranges from which the pictures were taken.



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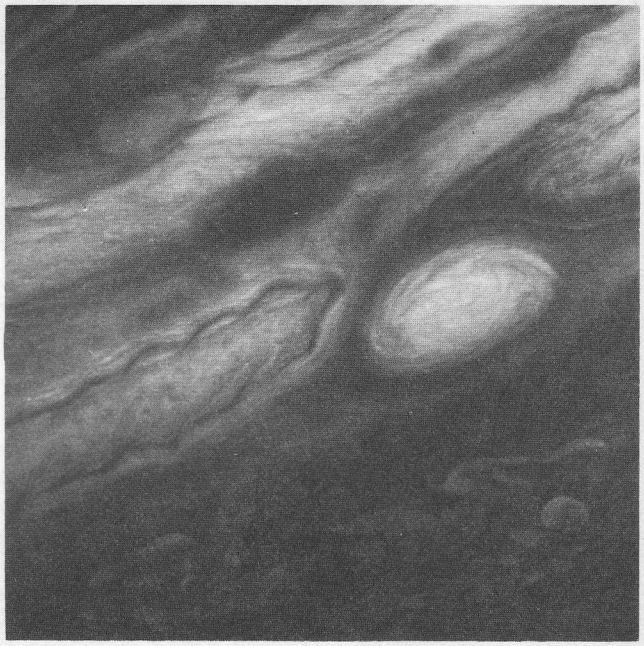
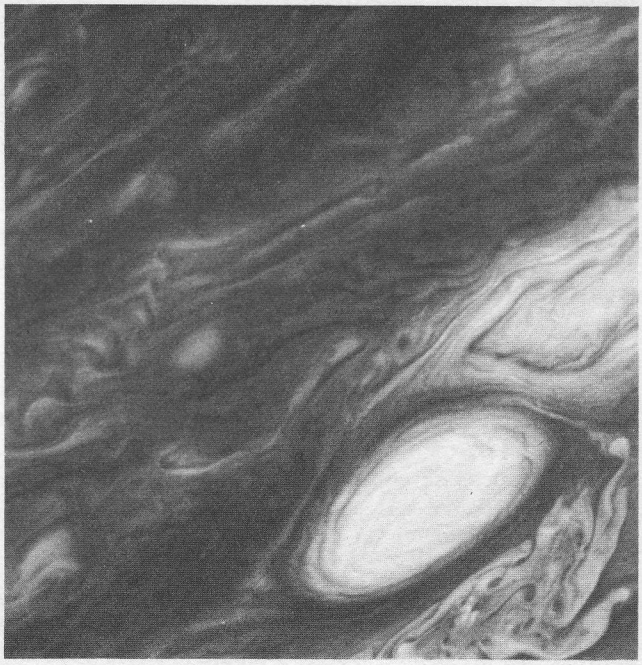
MISSION STATUS REPORT NO. 47 JULY 30, 1979





PARTS OF THE PUZZLE — Three white ovals observed to form in the southern hemisphere about 40 years ago have internal structure identical to that of the Great Red Spot first observed by Robert Hooke nearly 315 years ago.

The ovals travel across the planet at a different rate than the Great Red Spot; the white oval seen south of the Red Spot in the above Voyager 2 mosaic is not the same one seen there by Voyager 1 in March 1979. The oval in upper right photo is currently west of the Spot, while the oval in the photo at lower right is currently east of it.

The key to understanding Jupiter's atmospheric dynamics may be wave interactions with the mass flow. The longevity of some features could be due to internal heating. Infrared studies show that the Great Red Spot is cooler than the surrounding clouds.

The Great Red Spot and its three companion white clouds shown here all rotate anticyclonically (counterclockwise in the southern hemisphere), indicating that they are all meteorologically similar. Recirculating currents are seen to the east of all four features.

Since the bulk of Jupiter is comprised of transparent gases — hydrogen and helium — the coloration must come from the chemistry and dynamics of minor atmospheric constituents.

Current theories for the reddish color of the Great Red Spot suppose that phosphine (PH_3), a combination of one phosphorous atom and three hydrogen atoms, is converted by the sun's ultraviolet rays to red phosphorous (P_2 or P_4) when it reaches the top of the cloud.

The white ovals, about 13,000 kilometers (8000 miles) in diameter, are also very cold. They may be high-altitude clouds of ammonia crystals.

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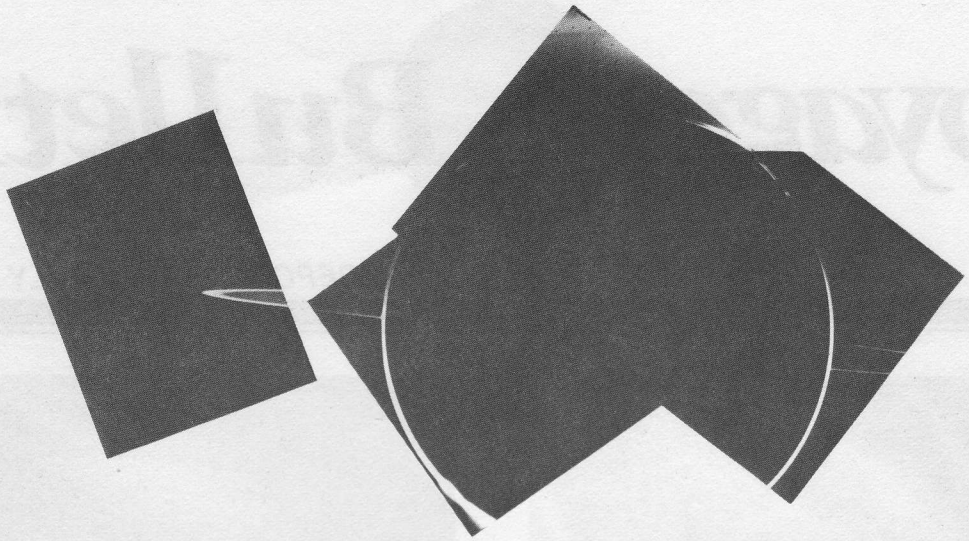


JUPITER'S HALO – From the dark side of Jupiter, backlit by the sun, the thin ring of particles discovered four months ago by Voyager 1 glows like a halo in this four-picture mosaic taken by Voyager 2 on July 10, 1979. Forward scattering of light from the ring's small particles give it its brightness, while the planet is outlined by sunlight scattered from a haze layer high in Jupiter's atmosphere. The ring particles appear to be small, leading to questions on how the ring survives. About 6500 kilometers (4000 miles) wide and four-tenths to eight-tenths kilometer (one-quarter to one-half mile) thick, the ring extends outward to about 53,000 kilometers (33,000 miles) from the top of Jupiter's cloud cover. There is structure within the ring extending all the way to the planet's upper cloud decks. Voyager 2 was about 1.5 kilometers (900,000 miles) beyond the planet when it returned these images to Earth during a search for lightning and auroras on the dark side.

Summary

Although Voyager 2 is three weeks beyond Jupiter and its marvelous satellites, the spacecraft is still very much in the Jovian system and continuing to gather information about the magnetic fields and charged particles on the leeward side of the planet (opposite the sun).

Two trajectory corrections (TCM's) this month, on July 9 and 23, have adjusted Voyager 2's flight path toward Saturn and Uranus. Now flying a route that will take it past Uranus in January, 1986, Voyager 2 will make its closest approach to Saturn about August 26, 1981.

Both of the TCM's were designed to take advantage of Jupiter's gravity to change the spacecraft's velocity and to bend its flight path. The maneuver on July 9 came only hours after closest approach to the planet, during concentrated imaging of Io designed to study volcanic activity on the puffing satellite. This was the first time Voyager had conducted active science measurements during a TCM.

Radiation Effects

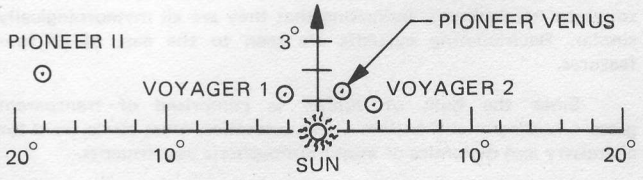
Encountering higher than expected radiation levels as it passed Jupiter, Voyager 2 experienced several problems, some of which are continuing and are still being investigated. The affected systems include the command receiver, the photopolarimeter instrument.

High radiation levels caused some expected problems in transmitting commands to the spacecraft near closest approach to the planet. Due to a failure in April, 1978, the ship's only remaining radio receiver is unable to follow a changing radio signal. Commands must be sent repeatedly, at varying frequencies, until the receiver locks up on the signal. (The signal frequency changes as it travels from Earth to the spacecraft due to the Doppler effect.) In addition, the receiver is sensitive to heating effects such as those caused by high radiation. The command receiver stabilized soon after closest approach and has operated well since.

The photopolarimeter instrument may also have experienced radiation damage. The instrument has three wheels (aperture, filter, and polarization analyzer) designed to give many combinations of observations. The filter wheel appears to be skipping every other position, reducing the number of available filters for observations. The polarization wheel was not operated at Jupiter because of problems earlier in the flight, but appears to have moved several positions from the open position in which it had been left. Color photometry may still be possible.

Solar Conjunction

Voyagers 1 and 2 will participate in high-latitude solar wind observations during August and September as the Earth moves to the opposite side of the sun from the spacecraft. As seen from the Earth, the spacecraft will appear to pass behind and slightly north of the sun, travelling a narrow path approximately one-degree wide.



ALL SPACECRAFT ON AUGUST 20, 1979

VERTICAL SCALE IS TWICE THAT OF HORIZONTAL SCALE

Radio signals from the spacecraft will pass through the northern solar corona, causing strong, measurable changes in the signals. Small-scale variations of plasma in the solar region will be studied, and the plasma density of the solar wind and corona will be mapped.

The Earth and most spacecraft orbit within seven degrees of the sun's equatorial plane. In August and September, a parade of planetary probes including both Voyagers, Pioneer 11, and Pioneer Venus will be aligned to provide multiple, correlating observations.

Voyager Bulletin

MISSION STATUS REPORT NO. 48 SEPTEMBER 12, 1979

Voyager 1 Wins Space Award

The Veterans of Foreign Wars of the United States have awarded their National Space Award Gold Medal and citation to the Voyager Project for the success of Voyager 1 at Jupiter last March. Accepting the award at the VFW annual convention in New Orleans was Mission Director Dick Laeser, standing in for R. J. Parks, project manager at the time of Voyager 1's Jupiter encounter. The text of the citation reads:

> *"A brilliant effort teaming professional knowledge, technology, and man's urge to conquer the unknown will lead to vehicles of human design to complete the initial reconnaissance of all the planets of the solar system in the first half century of the Space Age."*

Quiet Period Near an End

A six-week "quiet period" coinciding with the spacecraft's solar occultations is nearing an end. Due to the position of the Sun between Earth and the spacecraft, data reception from both ships has been poor, but the radio science team has taken this opportunity to study the effects of the Sun on the signals.

Voyager Watches Pioneer 11 and Saturn

"Come on through – the rings are great!"
(Pioneer 11 to Voyager)

A. Thomas Young
Deputy Director
NASA/Ames Research Center

As the world awaited word of its fate on September 1, Pioneer 11 swooped down past the outer edges of Saturn's rings, below the rings, past Saturn's cloud tops, and up again, out into deep space, with hardly a jolt to its systems.

Voyager 2 will take nearly the same path when it reaches the planet in August, 1981, crossing the ring plane at approximately the same point as Pioneer 11's inbound ring crossing.

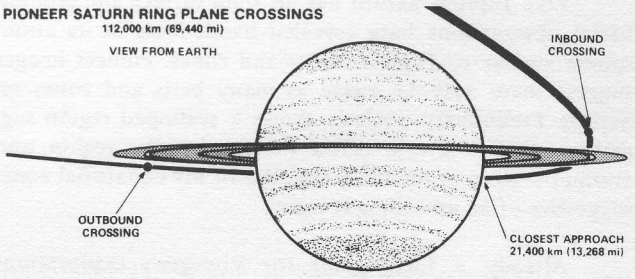
Many of Pioneer's findings will heavily influence detailed planning now underway for the Voyager flybys of Saturn. Of particular interest are the intensity of trapped radiation near the planet, the ring composition and density, rotation rates of material at various latitudes, and interesting weather features.

Ground-based telescopic observations have identified three or possibly four rings around Saturn, the second largest planet in our solar system and sixth in distance from the Sun. But the content of the rings has been the subject of much scientific debate – whether the particles are totally water ice or icy-coated rocks, how large, and how dense. Initial results from Pioneer 11 indicate that the rings may consist of many layers of snowball-sized particles which contain more water ice than rock.

In addition, Pioneer 11's imaging photopolarimeter detected a narrow ring of particles, the "F ring", outside the A ring, while the charged particle detectors reported a broader area, the "G ring", even farther from the planet. Unable to detect two other suspected rings (an outer E ring and inner D ring) from Pioneer, astronomers will study Saturn through telescopes this fall and winter when the rings will be edge-on to Earth.

When Pioneers 10 and 11 were rocked by sizzling and turbulent radiation along Jupiter's far-reaching magnetic field lines, the Voyager spacecraft were in the assembly stage. Parts were exchanged for more radiation-tolerant parts, electronic circuits were modified, additional radiation shielding was added to each spacecraft, and both Voyagers survived their passages near Jupiter with little damage.

The extent of Saturn's radiation was unknown until Pioneer 11's flyby. As the spacecraft passed below the



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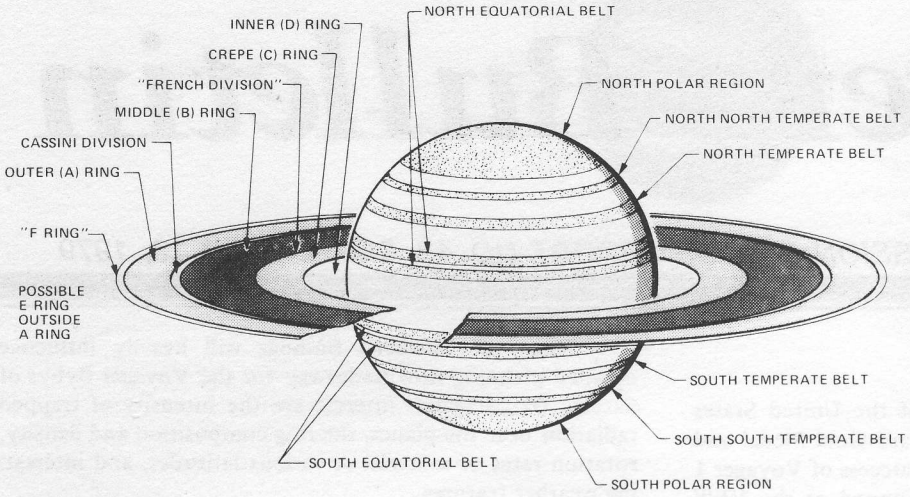

	km	mi
SATURN DIAMETER	119,000	74,000
FROM SATURN TO –		
C RING	12,570	7,810
B RING	31,730	19,720
CASSINI DIVISION	56,870	35,340
A RING	61,660	38,320
OUTER EDGE OF A RING	77,250	48,000
F RING	80,470	50,000

rings, the radiation intensity readings dropped dramatically, indicating radiation absorption by the rings.

Until Pioneer 11 crossed Saturn's bow shock on August 31 at a distance of about 1.4 million km (895,000 mi) from the planet, it was uncertain if Saturn even possessed a magnetic field. The bow shock is the line at which supersonic particles streaming from the sun are slowed to subsonic speeds near a planet's magnetic field boundaries. A planet's magnetic field tends to trap radiation particles and sweep them around in space with the planet's rotation.

Saturn's magnetic pole may be offset from its spin axis by as little as 1°, making it unique among planets. Most of the planets thus far studied have an offset of about 10°, causing a wobble in their rotating magnetic fields and allowing definition of precise longitudinal lines for mapping and tracking features.

Dynamo currents of magnetic fields are thought to exist in the metallic hydrogen below the outer gaseous atmosphere. Saturn's field source is deeper within the planet than at Jupiter, resulting in a more regular magnetic field.

The regular magnetosphere and low radiation levels bode well for the oncoming Voyagers.

Like Jupiter, Saturn has no solid surface and ground-based observations have revealed bandedness in its atmosphere similar to Jupiter's belts and zones. Pioneer images suggest there may be twice as many belts and zones on Saturn. Preliminary analysis shows a scalloped region suggestive of a jet stream below the north polar region, and another scallop at the northern edge of the equatorial zone, suggestive of an upwelling feature.

Already a focal point for Voyager's explorations because of its methane atmosphere, Saturn's largest satellite Titan has become even more interesting as it is sometimes inside, sometimes outside, Saturn's magnetosphere, due to varying pressure of the solar wind.

Ten minutes after crossing the ring plane on its inbound journey, Pioneer 11's charged particle instruments detected the deep shadow of a body with a radius of about 100 to 300 km at about 150,000 km (93,200 mi) from the planet's cloud tops. The spacecraft was about 2500 km (1550 mi) below the ring plane. This body may be the same as a body detected by the imaging system a few days earlier, and both may be sightings of Janus, the innermost and smallest of Saturn's ten known satellites.

Launched on April 5, 1973, Pioneer 11 was never intended to see Saturn. It was the second man-made object to successfully traverse the then-unknown region of the asteroid belt between the orbits of Mars and Jupiter, and also the second spacecraft to observe Jupiter, in December 1974. However, at that point, a decision was made to slingshot the sturdy craft 167 degrees back across the solar system to its bonus encounter with Saturn. In six years, Pioneer 11 has crossed two billion miles of space. Now it will head out of the solar system and toward the stars, in almost exactly the opposite direction of Pioneer 10, which encountered Jupiter in December 1973 and has already crossed the orbit of Uranus.

Weighing 258 kilograms (568 pounds) at launch, Pioneer 11 carries 12 instruments and conducts 14 investigations. Spinning constantly for stabilization (at a rate of 7.8 revolutions per minute at Saturn), Pioneer is powered by two radioisotope thermoelectric generators and carries a 9-foot-diameter dish antenna which points toward Earth to send and receive signals through the Deep Space Network.

The Pioneer missions are managed and controlled for NASA by Ames Research Center, Mountain View, California. The spacecraft was built by the Space Systems Division of TRW, Redondo Beach, California.

Pioneer 11's success strengthens Voyager 2's prospects of encountering Uranus in January, 1986. Voyager 2 is currently on a trajectory which will take it to Uranus after its Saturn Encounter in August 1981, but its flight path could be changed should Voyager 1 fail to meets its objectives at Saturn for any reason – including damage from radiation or ring particles, which now appears unlikely. Voyager 1's trajectory was chosen specifically to observe Titan at close range, while Voyager 2's flight path was specifically chosen to allow a flyby of Uranus.

Voyager Bulletin

MISSION STATUS REPORT NO. 49 OCTOBER 18, 1979

Make that 14 Known Jovian Satellites

NEW MOON — A new moon of Jupiter, the white streak to the right, was revealed in this computer enhanced photograph taken by NASA's Voyager 2 spacecraft on July 8, 1979 as the spacecraft flew past the giant planet. The moon, called 1979J1, orbits at the edge of the Jupiter ring seen in this photo as a gray diagonal band across the picture. The other white streaks are star tracks. Both the track of the moon and the stars are the result of a long exposure.

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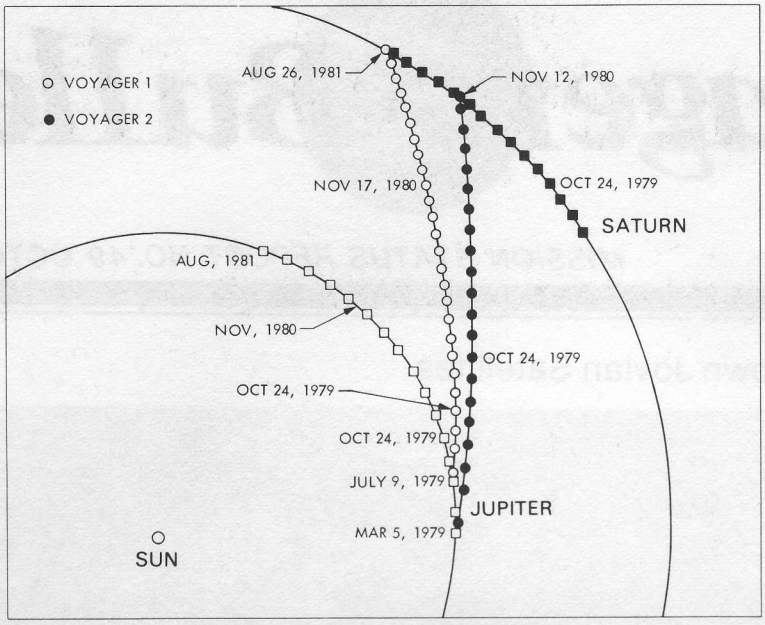

Make that 14 Known Jovian Satellites

Yet another phenomenon has been added to Voyager's already long list of discoveries – a fourteenth satellite at Jupiter.

The newly-identified satellite lies at the outer edge of the ring plane, but inside the orbit of Amalthea, at about 57,800 kilometers (36,000 miles) above Jupiter's cloud-tops. Estimated to be 30 to 40 kilometers (18 to 25 miles) in diameter, it has been temporarily designated 1979J1 (following the guidelines of the International Astronomical Union).

With an orbital period of 7 hours 8 minutes and a velocity of 30 kilometers per second (67,000 miles per hour), 1979J1 is the fastest moving satellite in the solar system.

Because of its proximity to the ring, there is speculation that the satellite may directly influence the composition of the ring by either supplying or sweeping out ring particles.

The discovery was made during analysis of photographs taken by Voyager 2 last July less than 24 hours before closest approach to the planet. Although the object in the photographs was initially thought to be a star trail, an exhaustive data search found no star in the vicinity. Another high resolution photograph of the same area showed the same portion of the ring, the same object, and trails of known stars. The differing angles and lengths of the star trails and the trail of the object led to verification that this was indeed a satellite.

Voyager Imaging Team member G. Edward Danielson of the California Institute of Technology (Caltech) and Caltech graduate student David Jewitt are credited with the discovery. The orbit was calculated independently by Jewitt and optical navigation engineer Stephen Synnott of JPL.

Another Caltech researcher, Charles T. Kowal, discovered Jupiter's 13th satellite in September 1974. Another possible moon may have been seen in Earth-based photos by Kowal several years ago and awaits confirmation.

UPDATE

Communications from Voyager 1 were temporarily lost on October 16 when the spacecraft did not acquire the star Canopus after a 22-hour cruise science maneuver. Cruise maneuvers are performed in a radio blackout since the antenna moves off Earth-line, but radio signals from the ship did not arrive at Earth when expected after the maneuver.

The cruise maneuver consists of steering the spacecraft through a series of 10 yaw and 25 roll turns to allow the fields and particles instruments to view the entire sky. Normally stabilized on three axes using the light intensities of the Sun and Canopus for reference, the spacecraft must lose lock on the star to perform the turns.

However, when the star tracker began its search for Canopus after the maneuver, it fixed on Alpha Centauri, mistaking it for Canopus. In this position, the antenna was pointed about 5° away from Earth.

When the situation was analyzed, the Tidbinbilla, Australia tracking station's powerful 80-kilowatt power carrier was used to send commands through the sidelobe of the spacecraft antenna to switch from the high gain antenna, which has a narrow beamwidth, to the wider beamwidth low gain antenna to make further commanding easier.

The spacecraft was then commanded to roll another 56.8 degrees. At the end of this roll, it was Earth-pointed and within 1 degree of Canopus. After the spacecraft signal was acquired at Earth, Voyager 1 was commanded to acquire Canopus as a reference star and to return to its high gain antenna.

Voyager Bulletin

MISSION STATUS REPORT NO.50 JANUARY 3, 1980

"An exciting, rewarding year has drawn to a close, and I would like to thank the Voyager Flight Team members and all the support groups for a job exceptionally well done. The results from Jupiter have sparked the world's interest and imagination. An equally challenging and exciting goal lies before us this year – Voyager 1's encounter with Saturn. With your continued dedicated support, I am sure we will be able to satisfy the high expectations established by our Jupiter successes."

Ray Heacock
Voyager Project Manager

Update

Voyager 1 Operations Back to Normal

Voyager 1's operations returned to normal on December 20, 1979, nearly seven days after the Saturn-bound spacecraft failed to re-orient its antenna toward Earth at the end of a course correction on December 13.

Currently 970 million kilometers (602 million miles) from Earth, Voyager 1 is Earth-oriented, responding to commands, and transmitting data. All science instruments are operating normally, and the trajectory correction itself was successful.

Voyager 1's failure to re-establish communications with Earth by regaining its celestial references has been traced to an internal communications error in the spacecraft. The combination of a mode change command word which violated computer sequencing constraints and a parity error touched off a series of events which caused the pre-programmed re-orientation sequence to halt. Since launch in September 1977, Voyager 1 has communicated over 37 million commands between the CCS and AACS (two on-board computers) with no previous parity error, which involves a bit-count check in the computer software.

The first indication of problems came at approximately 2:15 p.m. (PST) on December 13, when the Deep Space Network tracking stations did not receive the spacecraft signal as expected after the course correction. The maneuver is performed in a radio blackout since the high-gain antenna dish is turned away from Earth. A faint signal was detected through the DSN's special radio science equipment, and was tracked throughout the recovery.

At various times, commands were sent to switch the spacecraft's receivers and S-band transmitter from the high-gain antenna to the low-gain antenna, which has a much broader beamwidth.

During interplanetary cruise, the spacecraft normally stabilizes itself by tracking the Sun and the reference star Canopus. However, following the sequence abort, the spacecraft was stabilized by its internal gyros and was Sun-pointed only. It was initially assumed that the spacecraft was tracking a star other than Canopus, but two attempts to re-orient the spacecraft from possible stars failed.

On December 16, commands were sent to perform a "sun cone", searching for Earth by rotating the antenna around the Sun with an 8° offset, stopping at sixteen different points. At the third point, ground stations picked up a strong signal as the high-gain antenna beam swept across the Earth. Six minutes of data were received before the sequence continued to the next point. At completion of the search sequence, Voyager 1 was commanded back to the third point, and the signal was received by the Australian tracking station nearly 72 hours after the emergency began.

After analysis of the spacecraft's tape-recorded and computer memories data from the course correction and sequence abort, the spacecraft was commanded to return to its reference star Canopus on December 19, and by noon on December 20, all systems aboard Voyager 1 had been returned to normal.

Photopolarimetry Expected at Saturn with Voyager 2

Tests of Voyager 2's photopolarimeter on January 2, 1980, indicate that the instrument is stable and capable of limited operation. The instrument, which studies reflected sunlight to determine atmospheric, surface, and ring composition, will operate in two modes at Saturn (August 1981), collecting both color and polarization data. Earlier in the flight, the PPS experienced problems with its polarization analyzer wheel, and may have component damage due to Jupiter's intense radiation.

Voyager 1's photopolarimeter was declared inactive in December 1979 after tests indicated that its photomultiplier tube, which converts weak light signals to strong electrical signals, has virtually no sensitivity remaining. This fact, combined with an electrical problem in the motor drive circuit which turns the instrument's light analysis wheels, resulted in the decision to abandon the instrument. Analysts concluded that there would be little or no scientific value in any data this instrument could return.

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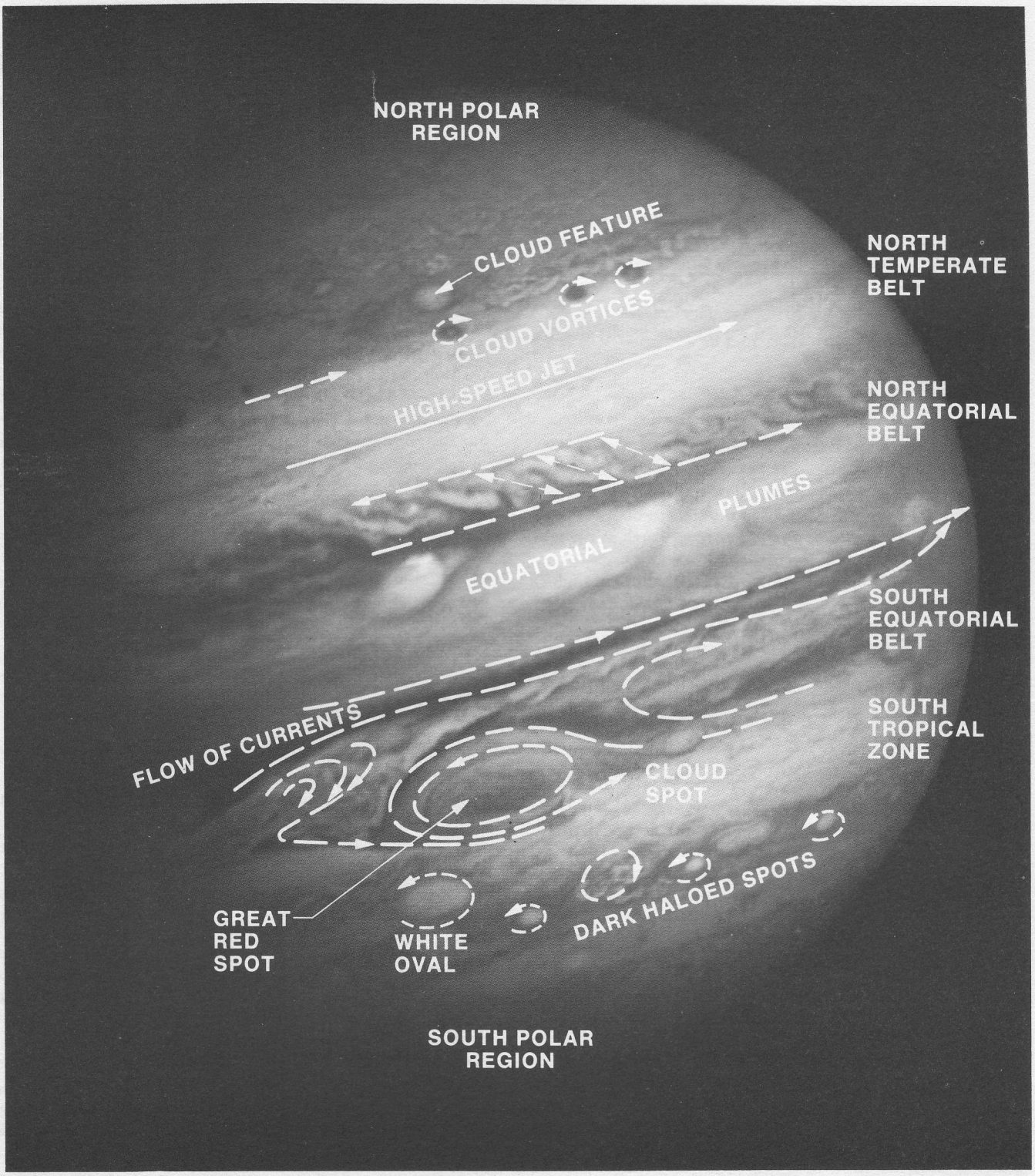
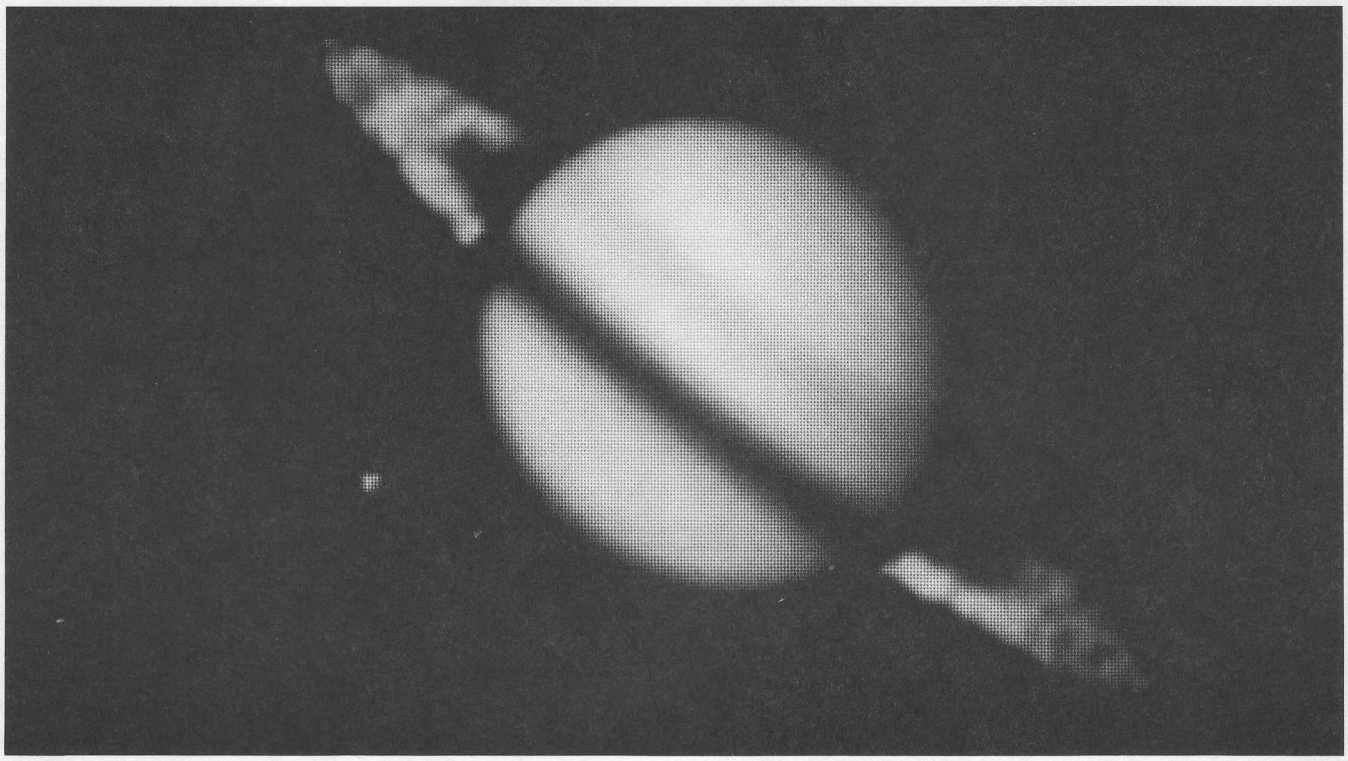

NORTH POLAR REGION
CLOUD FEATURE
CLOUD VORTICES
HIGH-SPEED JET
NORTH TEMPERATE BELT
NORTH EQUATORIAL BELT
PLUMES
EQUATORIAL
SOUTH EQUATORIAL BELT
FLOW OF CURRENTS
SOUTH TROPICAL ZONE
CLOUD SPOT
GREAT RED SPOT
WHITE OVAL
DARK HALOED SPOTS
SOUTH POLAR REGION

Voyager Bulletin

MISSION STATUS REPORT NO. 51, MAY 7, 1980



ITS SATURN! — Computer enhancement of this photo taken by Voyager 1 on March 20, 1980, shows Saturn's rings as well as one of its moons, Rhea (lower left). Voyager 1 was 312 million kilometers from the planet at this point.

President Carter Presents Goddard Trophy

America's most prestigious space award, the National Space Club's Goddard Memorial Trophy, has been presented to the Voyager Project by President Carter. In a March 24 ceremony at the White House, the president said:

". . . the team that's made this flight possible and also had such tremendous success in bringing the images and the knowledge so clearly back to Earth to be shared by scientists and others interested in astronomy and our own solar system, deserve (sic) the highest accolades."

Jupiter's Satellites: 15

A 15th satellite of Jupiter has been discovered in photographs taken by Voyager 1 in March 1979. Tentatively named 1979 J2, the satellite orbits between the satellites Amalthea and Io, about 151,000 kilometers above Jupiter's cloudtops. Its orbital period is 16 hours 16 minutes and its diameter is estimated to be about 70 to 80 kilometers.

1979 J2 was discovered by Stephen Synnott of the navigation team while verifying the existence of the 14th satellite, 1979 J1, discovered last fall in photographs from Voyager 2's encounter with Jupiter last July.

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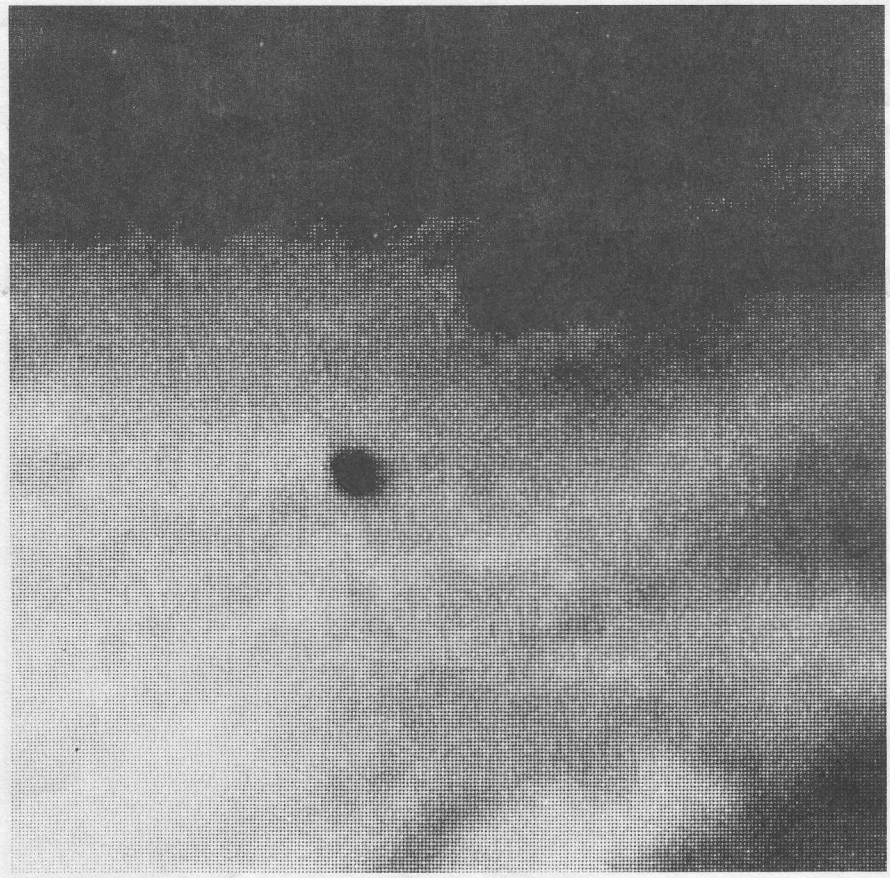


1979 J2 – The newly-discovered 15th moon of Jupiter (bottom) is seen with its shadow (top, at end of streak in clouds) against the face of the planet in this computer-enhanced photo taken by Voyager 1 on March 4, 1979. The satellite was discovered in April 1980 during continuing analysis of Voyager photos. It is 70 to 80 kilometers in diameter and orbits Jupiter every 16 hours 16 minutes at a distance of 151,000 kilometers above the cloudtops. This is the second satellite discovered from Voyager data; the first was found last October.

Update

Both Voyagers are in good health and on target for their respective Saturn encounters. Routine calibrations and tests, as well as sampling of the interplanetary medium, continue for both spacecraft, while Voyager 1 is taking periodic images of Saturn for calibration and navigation purposes.

Voyager 1 performed a cruise science maneuver on February 20, 1980, making a series of yaw and roll turns to allow calibration of the magnetometer and other instruments to view the entire sky. The maneuver was entirely successful; however, analysis of the telemetry showed slight differences from the predicted command issuance between the two computer command subsystem processors. This is the fourth instance of command problems aboard Voyager 1 since Jupiter encounter; therefore, a Spacecraft Anomaly Team has been formed to further investigate the on-board command problem. The team will assess the adequacy of current immediate protection programmed into the on-board computers; determine what diagnostic tests might be conducted; determine what failure or noise mechanism could have led to the observed problems; and investigate the feasibility of additional fault protection measures. The team's study should be completed by July 1, allowing time for corrective measures before the Saturn encounter activities begin in late August. Voyager 1 is scheduled to move off Earth-line several times during the encounter period with a high internal command activity, thus driving the necessity to implement protective measures to assure a successful Saturn encounter.

Safeguards for Voyager 2's mission have also been implemented. An updated "backup mission load" (BML) program is now stored in the spacecraft's computer command subsystem. This load will activate should Voyager 2 lose its remaining command receiver before Saturn encounter. The program provides a tremendous improvement over the previous BML in the amount of science data that would be returned from Saturn, and extends the data-gathering capability beyond Saturn to Uranus.

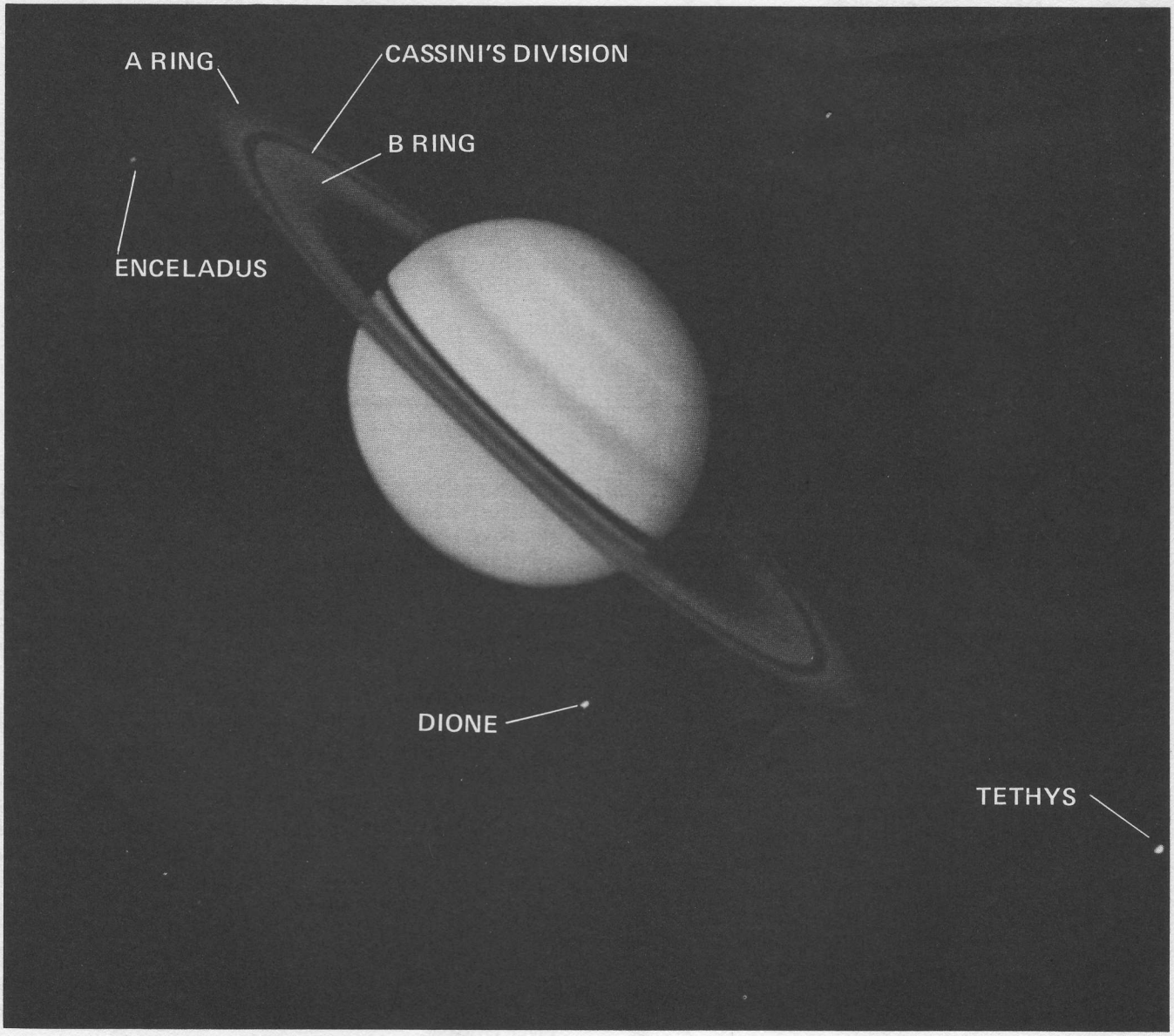
Both spacecraft are well within the power and fuel allocations for their respective missions. Before launch, each ship was loaded with 105 kilograms of hydrazine fuel. This propellant is stored in a tank mounted inside the ring of electronics compartments and carried to the thrusters via "plumbing" lines.

Three radioisotope thermoelectric generators (RTG) on each spacecraft convert the heat from nuclear fuel decay to electrical energy to operate the engineering and science mechanisms. Developed by the U.S. Department of Energy, such "atomic batteries" provide power for missions travelling distances too far from the Sun to utilize solar cell arrays for power conversion. The nuclear fuel for the generators is plutonium dioxide which is chemically-inert and has a long half-life (87.8 years) and low-shielding requirements. Heat generated by the radioisotope fuel is converted into electrical energy by silicon germanium thermocouples: The RTGs are kept at a constant electrical load by the power subsystem, which dumps excess power into space as heat. Power output aboard the spacecraft is now about 438 watts. The power usage of the science instruments at Saturn will be about 99 watts.

Signals between Earth and Voyager 1 now travel 61 minutes 19 seconds one-way. The spacecraft is about 1.1 billion kilometers from Earth, and its velocity (with respect to the Sun) is 21 kilometers per second.

Voyager Bulletin

MISSION STATUS REPORT NO 52 AUGUST 27, 1980



OBSERVE: SATURN — Voyager 1's encounter with the planet Saturn has begun with a series of photos, among them this one of Saturn and three of its satellites. The picture was taken August 24, 80 days before closest approach, when Voyager 1 was 106,250,000 kilometers (66 million miles) away. A series of dark and light cloud bands appears through high-altitude atmospheric haze in the northern hemisphere. Considerable structure can be seen in the rings: Cassini's Division, between the A-ring and B-ring, is readily visible. The shadow of the rings on the planet's disk can also be seen.

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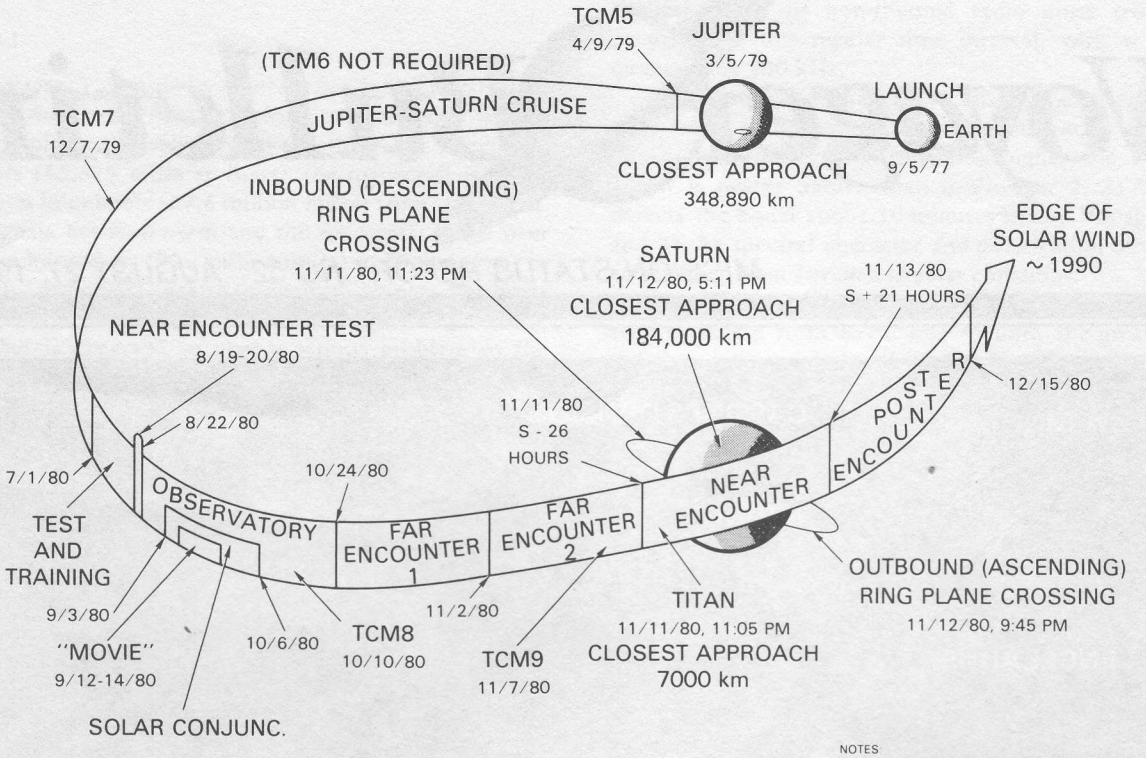
Recorded Mission Status (213) 354-7237
Status Bulletin Editor (213) 354-4438
Public Information Office (213) 354-5011



NOTES
1. TIMES ARE EARTH-RECEIPT OF SIGNAL. PACIFIC STANDARD TIME
2. DATES ARE GREGORIAN CALENDAR
3. DISTANCES ARE FROM CENTER OF BODIES
4. ONE WAY LIGHT TIME = 1 HR 24 MIN 47 SEC AT SATURN CLOSEST APPROACH
5. TCM = TRAJECTORY CORRECTION MANEUVER

Saturn Encounter Phases

The Saturn Encounter activities have been divided into five phases, arbitrarily chosen based on the field of view of the narrow angle camera in relation to the distance to the planet. The five phases are Observatory, Far Encounter 1, Far Encounter 2, Near Encounter, and Post Encounter.

Observatory starts August 22, about 82 days before closest approach, and runs nine weeks. During this period, a long time base history of the Saturn system will be compiled.

Daily ultraviolet scans of the system will search for hydrogen sources. The fields and particles instruments will monitor the interplanetary medium near Saturn.

Two time-lapse movies will be compiled from photographs taken during this period. Color "zoom" movies will be compiled from photographs taken every 2 hours 3.2 minutes over about two months. These movies will focus on five longitudes as the spacecraft "zooms" in on the planet. A second color movie will be compiled from photographs taken every 4.8 minutes during a 42-hour period September 12-14, covering four Saturn rotations.

Radio experiments to study the sun's corona will be performed during solar conjunction, when the sun will be between the Earth and spacecraft. From September 3 through October 6, the angle defined by Voyager, the earth, and the sun, will be 15 degrees or less, hampering radio communications, but allowing study of the sun as the radio signals pass through its corona.

A trajectory correction maneuver to adjust the flight path will be done on October 10. Numerous other calibrations will also be done during the Observatory phase.

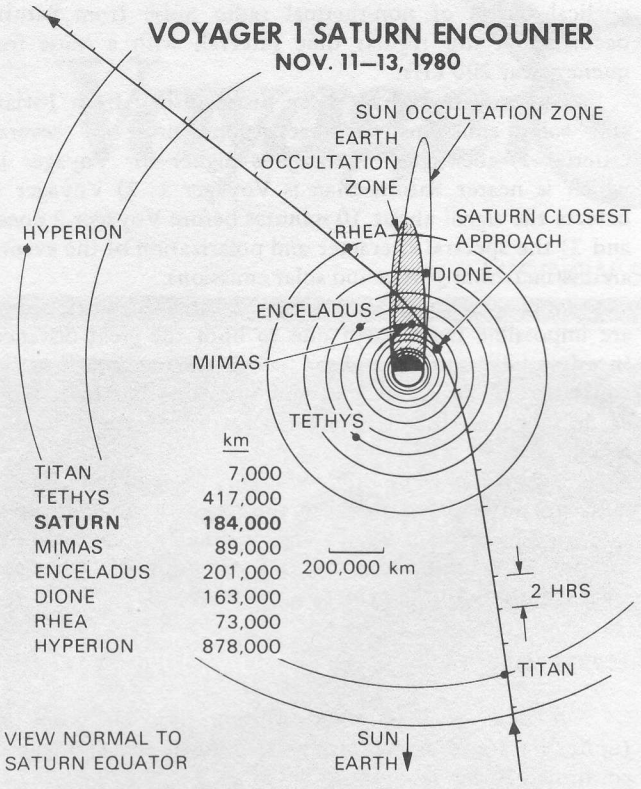
By October 24, 19 days before closest approach, the narrow angle camera's field of view will no longer capture the entire planet in one frame. Two by two mosaics (four pictures to cover the entire planet) will signal the start of the next phase, **Far Encounter 1**. Voyager 1 will be 16 million miles from the ringed planet.

Within another ten days, the **Far Encounter 2** phase will begin when 2x2 mosaics no longer suffice to cover the entire planet. On November 2, Voyager 1 will be 8.8 million miles from Saturn. The final Voyager 1 trajectory correction maneuver is scheduled for November 7.

The 47-hour **Near Encounter** phase begins November 11, 26 hours before Saturn closest approach, and runs through November 13, 21 hours after closest approach. At approximately 11:05 p.m. PST on November 11, signals from Voyager 1's closest approach (7000 km) to Titan will arrive at Earth. Eighteen minutes later, the spacecraft will dip below the ring plane. Eighteen hours after Titan closest approach, Voyager 1 will make its closest approach to Saturn on November 12. It will be below the rings, 184,000 km from the shadowed southern hemisphere. The signal will reach Earth about 5:11 p.m. Four and a half hours later, Voyager 1 will make its outbound, ascending ring plane crossing.

Voyager 1's observations of Saturn will continue in the **Post Encounter** phase through December 15. It will then continue to observe the interplanetary medium for as long as we can track the spacecraft, participating in celestial mechanics and solar experiments with other interplanetary spacecraft still being tracked.

If Voyager 1 is still being tracked ten years hence, we may observe the edge of the influence of the sun's magnetic field, some 20 to 30 times farther from the sun than Earth is. Voyager 1 will be on a solar system escape trajectory that will take it out of the ecliptic plane – that plane in which most of the solar system's bodies lie.

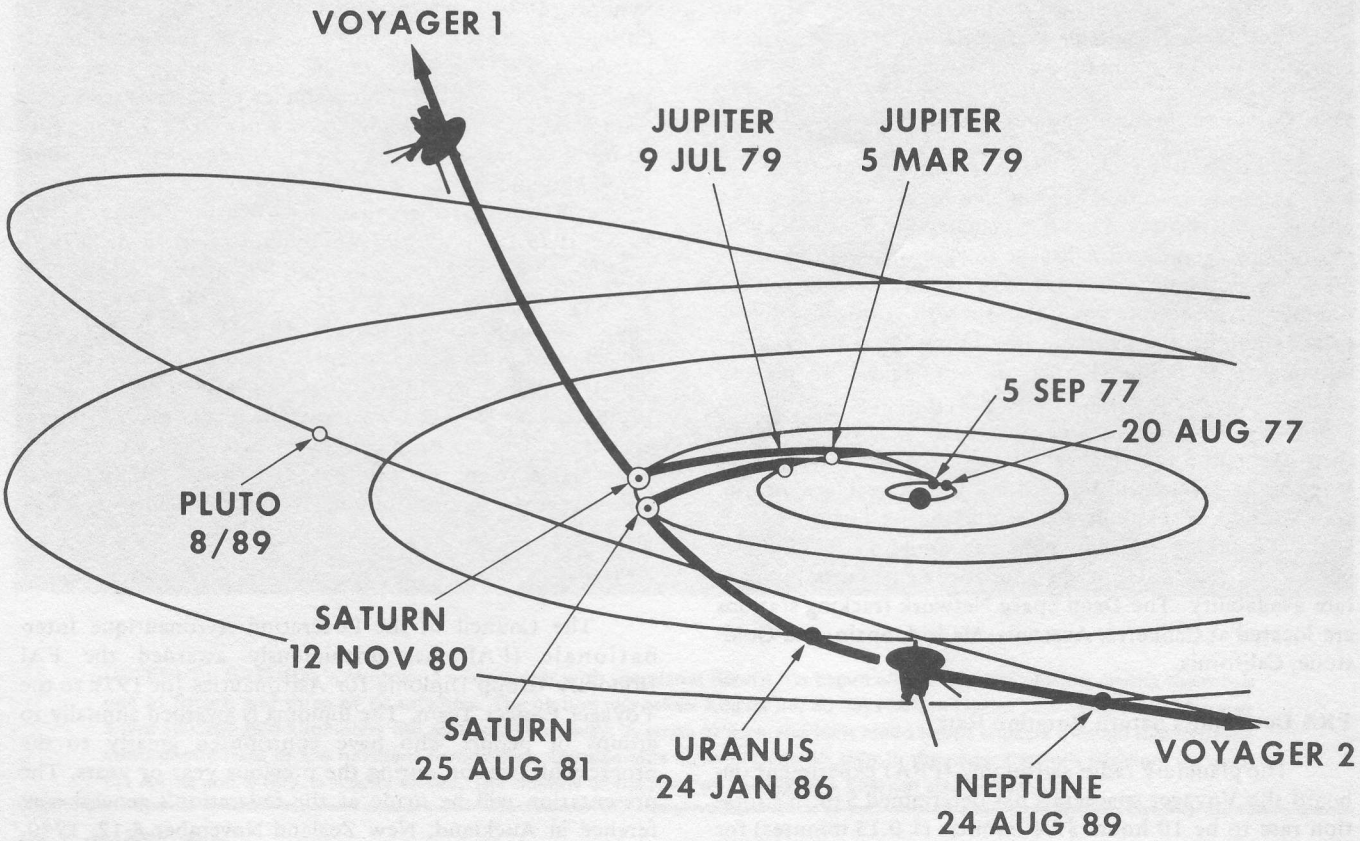


Note: Distances are approximate closest approach measured from center of body. Saturn closest approach will be about 184,000 km from the center of the planet, or 124,000 km from the cloudtops, using a Saturn radius of 60,000 km.

Test and Training

The Voyager Flight Team has been certified ready for Saturn Encounter operations after a seven-week test and training period. A key part of test and training was simulations of Murphy's Law No. 1: "Whatever can go wrong, will go wrong, at the worst possible time." Some of the simulated problems included fire in the mission control area during planned commanding, requiring relocation of operations to another building; incorrect real-time command requests; ground-based computer failure during satellite pointing updates and optical navigation; apparent propulsion hardware failure during a simulated trajectory correction maneuver; bad data from an instrument; and spacecraft computer failures. A prime objective of the test and training period has been to sharpen all skills so that nothing is done by rote.

Test and training climaxed August 18-19 with the Near Encounter Test, a simulation of 18 hours of the period of closest approach to Saturn. A near-duplicate of the near encounter computer sequence was sent to Voyager 1 and activated. Alternate pointing commands were issued to the scan platform to avoid pointing the cameras directly at the sun during the test. At Saturn, the planet will block the sun's light during these sequences, giving occultation data. The spacecraft will be oriented by its inertial gyro system during the near encounter phase, as there will be several spacecraft maneuvers about the roll, pitch, and yaw axes.



MISSION PLAN – After its flyby of the Saturn system in November, Voyager 1 will be on an escape trajectory from the solar system which will carry it above the ecliptic plane. Voyager 2 will reach Saturn in August 1981 and then has the opportunity to continue to encounters with the planets Uranus and Neptune. Neither ship will come close to the solar system's ninth planet, Pluto, in its 248-year trip around the sun.

Update

Voyager 1

Voyager 1 began its concentrated observations of Saturn on August 22, 82 days before its closest approach to the ringed planet. Travelling with a heliocentric velocity of 20.4 km/s (45,675 miles an hour), the spacecraft is about 109 million kilometers (67.6 million miles) from the planet. Radio signals between earth and the spacecraft travel over 1.4 billion kilometers (901 million miles) in 80 minutes.

The spacecraft has experienced minor hardware problems in the Canopus star tracker and the scan platform, but neither is expected to pose a serious problem to the planned Saturn encounter activities.

Voyager 1's Canopus star tracker has a problem which limits its available fields of view. Investigation into the problem shows that all required stars can be tracked, with the possible exception of the star Vega which is required after Saturn closest approach. The back-up star tracker has been tested and could be used if needed after appropriate calibrations are completed.

The Canopus star tracker helps stabilize the spacecraft and keep it properly oriented by tracking the earth, sun, and a reference star (nominally Canopus).

In addition, Voyager 1's scan platform has experienced a "creep" of 0.17 degrees for negative slews in the elevation axis. The creep seems to occur over a one to four hour period, when it occurs. Several solutions which will eliminate any concern from this problem are under consideration.

Voyager 2

Voyager 2 continues in interplanetary cruise. Its operations during its sister craft's Saturn activities will be limited to routine calibrations and navigation.

DSN Completes Station Updates

All three Deep Space Network stations now boast one each 26-, 34-, and 64-meter antennas. One 26-meter antenna at each station has been enlarged to 34 meters. The enlargement greatly expands the tracking capabilities of the network, as the distances to the spacecraft increase and the number of spacecraft being tracked also grows. By electrically combining the signals received by a 34- and a 64-meter antenna (a technique known as arraying), a 28 percent increase in received signal strength is realized over that achievable with a 64-meter station alone. Even with this improvement, the highest data rate achievable from Voyager at Saturn will be 44.8 kilobits per second, in contrast to the 115.2 kilobits per second received from Jupiter. Without arraying, the maximum rate would be 29.9 kilobits per second. The extreme distance involved lowers the data rate availability. The Deep Space Network tracking stations are located at Canberra, Australia; Madrid, Spain; and Goldstone, California.

PRA Determines Saturn Rotation Rate

The planetary radio astronomy (PRA) experiment onboard the Voyager spacecraft has determined Saturn's rotation rate to be 10 hours 39.4 minutes (± 0.15 minutes) for the bulk of Saturn. Earth observations had shown similar periods for temperate and polar regions of Saturn, but a much shorter (10 hours 14 minutes) period near the equator, indicating the presence of a high-velocity equatorial jet stream.

Correlation of data taken by both spacecraft shows cyclical bursts of non-thermal radio noise from Saturn occurring at this regular time interval, with a noise frequency near 200 kHz.

The emissions have been distinguished from Jovian and solar emissions and background noise by several criteria: 1) the signal intensity is higher for Voyager 1, which is nearer Saturn than is Voyager 2; 2) Voyager 1 detects the signal about 10 minutes before Voyager 2 does; and 3) the spectral character and polarization of the events are distinct from Jovian and solar emissions.

Such precise measurements of Saturn's rotation rate are impossible from Earth due to both the great distance (nearly a billion miles) and the fact that Saturn's peak radio emissions fall in a radio communications band used on earth. Pioneers 10 and 11 did not carry this type of instrumentation.

Saturn has been thought to have a regular magnetic field and little offset between the magnetic pole and spin axis (Earth's offset is 23.5°), but the ability to determine a rotation rate for Saturn implies a deviation from perfect axial symmetry of the planetary magnetic field.

1979J3 Makes 16

A new small satellite orbiting near the edge of Jupiter's wafer-thin ring brings to sixteen the number of confirmed Jovian satellites.

The new satellite, 1979J3, orbits about 56,200 kilometers above the cloudtops with a period of 7 hours 4.5 minutes and a velocity of 31.5 km/s. Its diameter is about 40 kilometers.

Discovered by JPL optical navigation engineer Steve Synnott, 1979J3 was assumed to be 1979J1 when found during a search to confirm the orbit of that satellite last March. 1979J1, discovered last fall in photos taken by Voyager 2 in July 1979, has similar characteristics with a diameter of 30 to 40 kilometers, a period of 7 hours 8 to 10 minutes, and an orbit at the outer edge of the ring some 57,800 kilometers above the cloudtops.

This spring, when checking Voyager 1 pictures from March 1979 to verify 1979J1, Synnott discovered 1979J2, another small satellite 70 to 80 kilometers in diameter orbiting between Amalthea and Io. At that time he also sighted an object thought to be 1979J1. However, further crosschecking between Voyager 1 and 2 photos showed that this object would have been on the opposite side of Jupiter from 1979J1's position when Voyager 2 photographed it. This led to the discovery of 1979J3.

Many scientists feel that such small satellites may influence the composition and stability of planetary rings.

Awards

The Council of the Federation Aeronautique Internationale (FAI) has unanimously awarded the FAI Honorary Group Diploma for Astronautics for 1979 to the Voyager Project Team. The diploma is awarded annually to groups of people who have contributed greatly to the progress of aviation during the previous year or years. The presentation will be made at the federation's general conference in Auckland, New Zealand November 8-12, 1980.

Raymond L. Heacock, Voyager project manager at JPL, has accepted the James Watt International Medal awarded by the Institution of Mechanical Engineers in England. The presentation was made June 25, 1980 at the institute's London headquarters.

Voyager Bulletin

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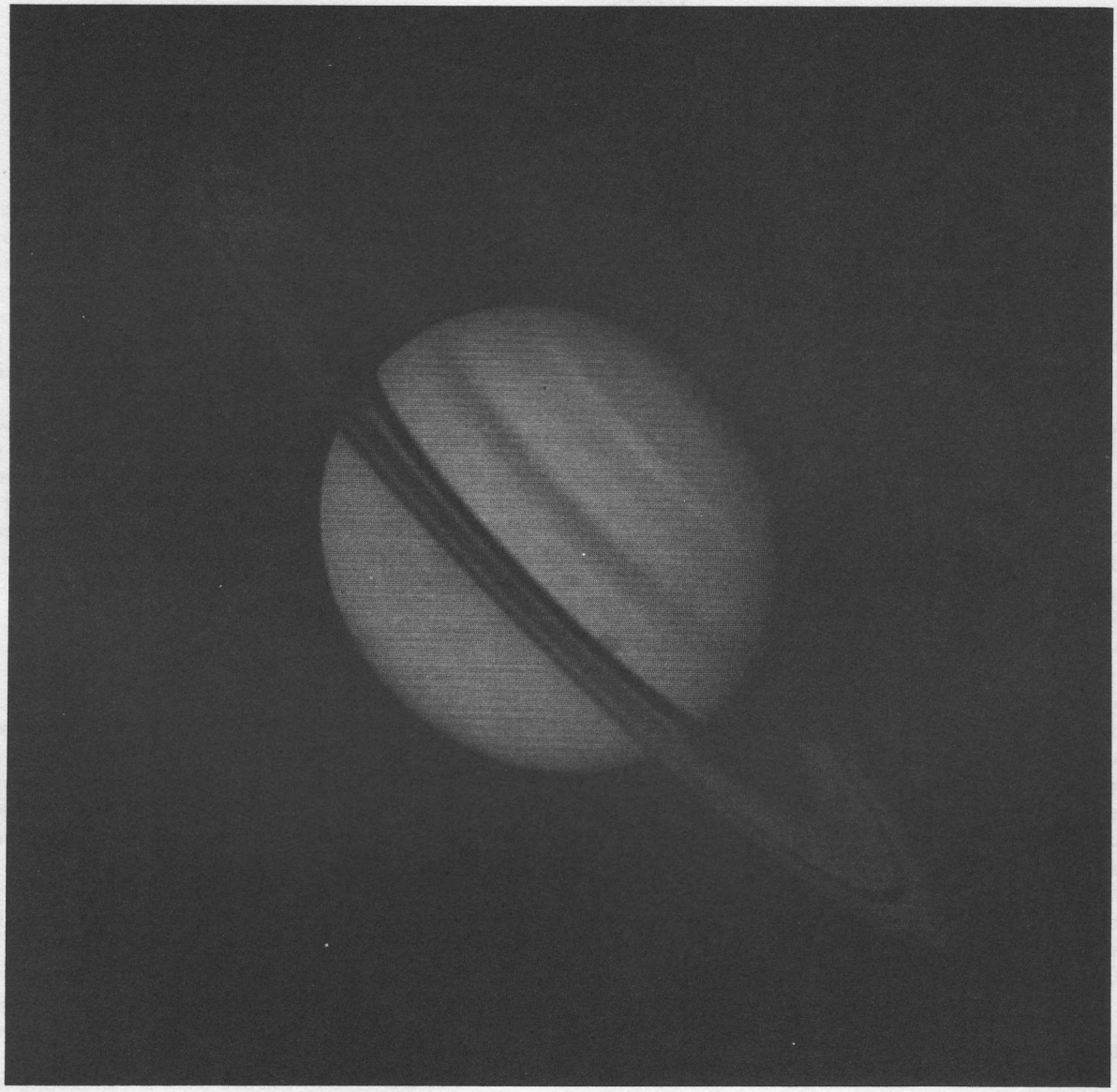

IN THE MOVIES — Nearly nine weeks before its closest approach to Saturn, Voyager 1 photographed four continuous rotations of the planet. This picture, taken September 12 from a range of 81 million kilometers (50.5 million miles) is part of that sequence. Very obvious are numerous bands in Saturn's atmosphere, the Cassini and Encke Divisions in the rings, the rings' shadow on the planet, and the planet's shadow on the rings (right). The Cassini Division is the more prominent gap in ring brightness, while the Encke Division is the fainter gap near the ring tip. Where the rings cross the face of the planet, the planet can be seen through the Cassini Division and the C-ring, the less dense ring between the cloudtops and B-ring. At the current sun illumination angle of 3°, the rings appear much darker than the planet itself, quite unlike most earth-based photographs.

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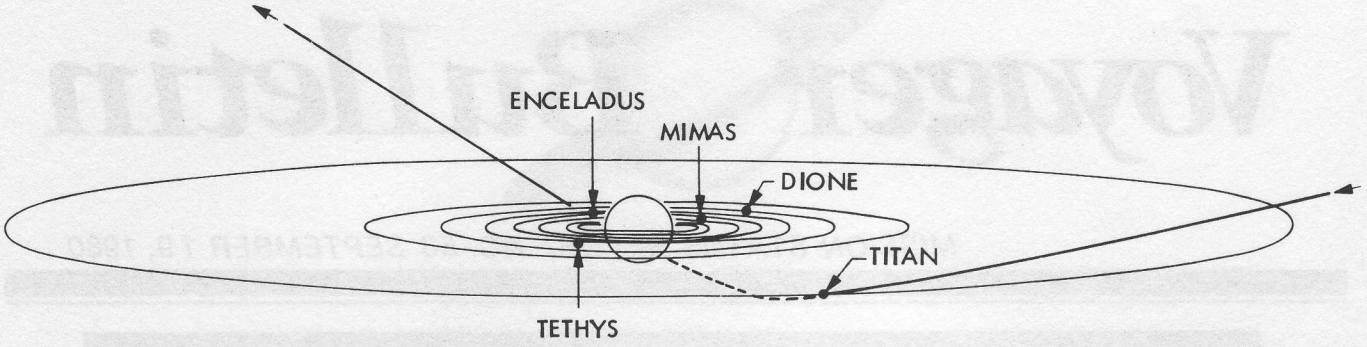

BENEATH THE RING PLANE – On November 11, Voyager 1 will pass about 4330 kilometers (2500 miles) from Titan's clouds, and then will dip below the ring plane. About twenty-two hours later, on its outbound leg, Voyager 1 will rise above the ring plane once again, passing through an area where Dione is thought to clear a path through the E-ring particles.

Update

Voyager 1 continues to build a data bank with its repetitive observations of the Saturn system. Sweeping across the system seven times a day, the ultraviolet spectrometer will provide information on the chemical constituents in the system, including any concentrations such as tori or clouds. The infrared spectrometer and radiometer is gathering infrared composition data on the atmosphere, thermal structure, and dynamics of Saturn. Two frames of planetary radio astronomy data are returned daily, recorded at 115.2 kilobits per second. Planetary radio astronomy data helped determine the radio rotation rate of Saturn, 10 hours 39.4 minutes. The cameras continue photographing the planet every 72° longitude, taking five images every 2 hours 3.2 minutes. Each of the five images is taken through a different filter – blue, orange, green, ultraviolet, and violet – for later color reconstruction. This long-time base set of images could be compiled into as many as five time lapse movies, each of which zooms in on one longitude of the planet. Photographs taken at long exposures through the clear filter three times each day are being used to search for several small new satellites to update the camera pointing for later photography. Routine calibrations also continue.

Voyager 2 is now cruising quietly, having received the computer sequence which will carry it through Voyager 1's busy encounter period. Routine calibrations will be performed, as well as solar conjunction experiments.

Four Rotations Imaged

Four rotations of Saturn have been captured by Voyager 1's narrow-angle camera and will be processed to make a color rotation movie before closest approach to the planet in November.

Voyager 1 photographed Saturn continuously for about 42 hours on September 12 - 14, returning pictures every 4.8 minutes. The images were taken through a set of three different filters every eight degrees of rotation.

This Saturn rotation movie will show less detail in the planet's atmosphere than did the Jupiter color rotation movie, due to both the distance and the high altitude haze at Saturn. Voyager 1 was about 81.2 million kilometers (50.5 million miles) from Saturn at the start of this movie sequence, in contrast to its Jupiter range of about 34.7 million kilometers (21.6 million miles). One reason is the need to capture the rings in the field of view in hopes that motion in the rings will be apparent in the time lapse movie. Jupiter filled about 480 pixels (picture elements) of the 800-pixel imaging frame; Saturn, from ring edge to ring edge, filled about 420 pixels. The movie could not be done later due to radio interference during solar conjunction.

In addition, a high altitude haze obscures detail in the planet's atmospheric structure. Nearly twice the distance from the sun as Jupiter, Saturn is much colder, and particulates in the atmosphere precipitate out lower in the clouds. Saturn's wind velocities are also greater than Jupiter's, perhaps resulting in shorter-lived features in the atmosphere.

Solar Conjunction

As seen from the spacecraft, the earth has now passed within 2° of the sun in its yearly orbit. Radio signals between earth and the spacecraft have passed within 5° of the sun since mid-September, resulting in poorer communications but also opportunities to study the sun's corona by its effects on the signals.

The period designated "solar conjunction" is that period when the angle measured from the sun to the earth to the spacecraft is 15° or less. When the angle is 5° or less, the "noise" in the radio signal is at its highest level. This period is September 12 - 23 for Voyager 2 and September 17 - 27 for Voyager 1. The smallest angle will be about 1.87° for Voyager 2 and 2.04° for Voyager 1.

Voyager's radio science team is conducting measurements of the solar corona's spatial and temporal variations by examining the corona's effects on the radio signals between earth and the spacecraft. Data is also being taken to test one aspect of the general theory of relativity which predicts that the radio signal will be delayed as it passes through the near-sun gravitational field. According to Einstein's theory, radio signals passing near the sun should be slowed in their round trip between earth and the spacecraft by about 0.0002 seconds. With special equipment located at the Deep Space Network tracking stations, the size of the delay can be measured to within one ten millionth of a second. Round trip light time for Voyager 1 is now approximately 2 hours 47 minutes. An opportunity to test the theory with such high precision has not existed since the Viking mission in 1976.

Voyager Bulletin

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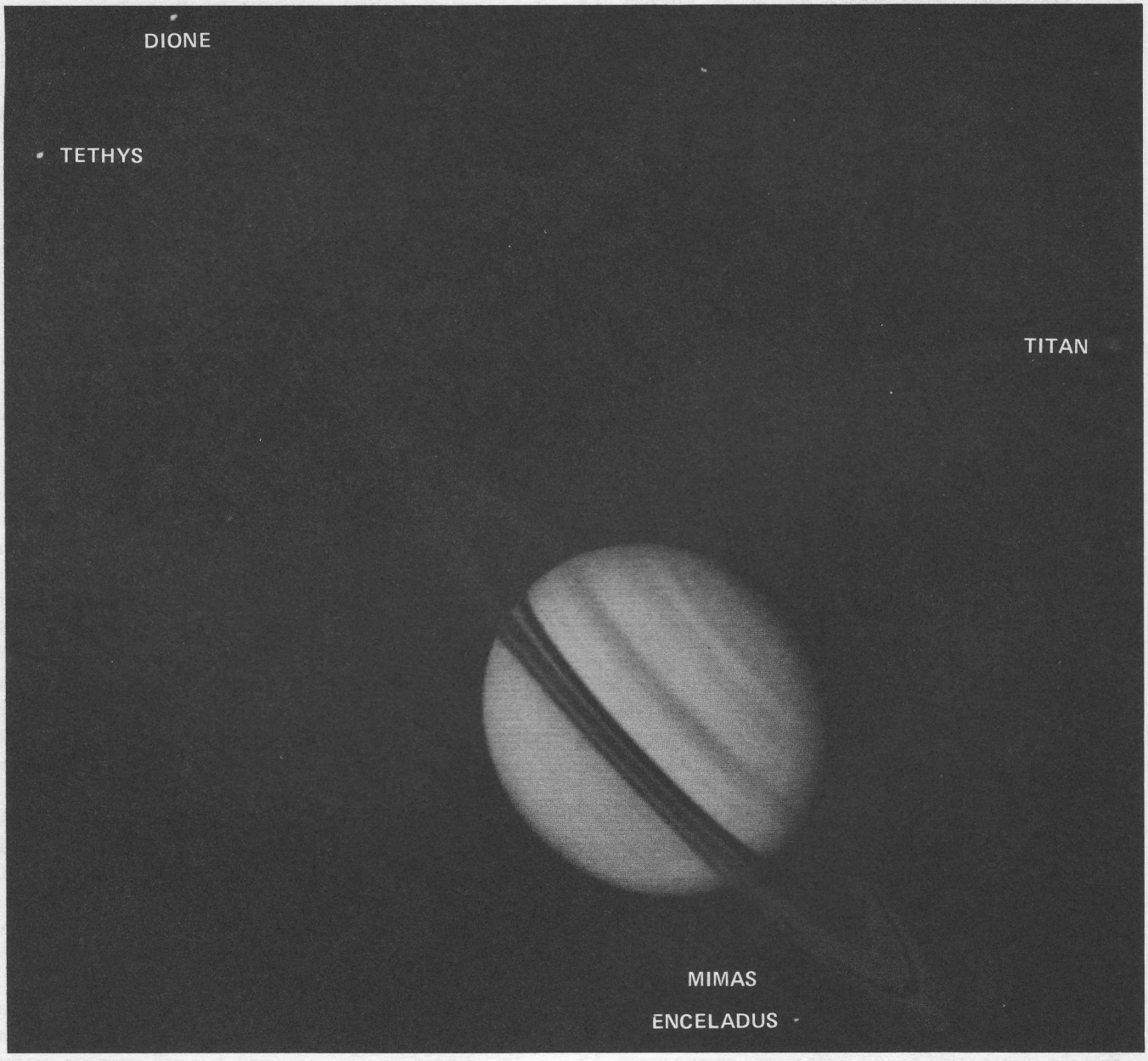

Voyager 1
September 17, 1980
Range to Saturn: 76 million kilometers

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UPDATE

Voyager 1 will perform a planned trajectory correction maneuver on October 10. The thrusters will fire briefly to accelerate the spacecraft about 2 meters per second and to change its course slightly. Without this approximately 13.7-minute burn, the spacecraft would be on a collision course with Titan, Saturn's largest satellite. Voyager 1 is scheduled to swoop about 2500 miles above Titan's clouds on November 11. A final course correction is scheduled for November 7 if needed to "fine tune" the flight path.

Only two more weeks remain in Voyager 1's "Observatory" phase consisting of routine, cyclical observations of the Saturn system. Picture resolution is now about 1640 kilometers, compared to about 5000 kilometers for the best Saturn photograph ever obtained from earth. On October 24, the cameras will begin four-picture (2 X 2) mosaics of the planet and rings.

As the spacecraft nears the Saturn system, a search for new satellites will continue. Two small satellites are thought to orbit at the same distance as Dione, one trailing several degrees behind and the other leading several degrees ahead. Sets of two (i.e., 1 X 2 mosaics) long-exposures through the clear filter will be used to try to capture images of these satellites and the rings. The pictures will be used primarily to calculate the orbits more precisely and to provide coverage of the rings which are beginning to overflow the narrow-angle camera's field of view as Voyager 1 nears the planet.

SATURN

> "There is not perhaps another object in the heavens that presents us with such a variety of extraordinary phenomena as the planet Saturn: a magnificent globe . . ."
>
> –Sir William Herschel
> in **Singular Figure of Saturn** (1805)

Herschel was among the many through the ages who have been fascinated by the sixth planet, its nest of rings, and its covey of satellites. Over 2600 years of observations have yielded volumes of knowledge on the Saturn system, but this steady flow of learning is about to accelerate tremendously as Voyager 1 homes in.

One of the solar system's four outer planets known as the "gas giants" (along with Jupiter, Uranus, and Neptune), Saturn is unique in its extremely cold atmosphere with high-speed winds; its nested set of rings; and its mismatched set of moons.

These outer planets are huge accumulations of helium and hydrogen with small rocky cores. Saturn's overall density is about seven-tenths that of water – which means that the planet could float if there were a cosmic ocean. An enormous balloon of hydrogen and helium, Saturn could hold about 770 earths – but is only 95 times heavier than earth.

Current models of Saturn's interior suppose a small, heavy, rocky core which may be twice earth's size but 15 to 20 times heavier due to large concentrations of rock and iron. Pioneer 11 measured the core radius at 13,800 kilometers (8,575 miles). Enveloping the core is a form of electrically conductive liquid metallic hydrogen not found on earth because of the great temperatures and pressure required to produce it. Beyond this is a shell of hydrogen and helium to the cloudtops, with heavier helium sinking through to the interior hydrogen.

Several other gases are known to exist at Saturn, including heavy hydrogen (deuterium), methane, ethane, and phosphine. Helium has not been confirmed, but its existence is inferred from other factors.

Saturn is indeed an oblate spheroid, with flattened poles and a bulging equator. About 5800 kilometers (3600 miles) difference has been measured between the polar and equatorial radii. The generally accepted equatorial radius is 60,300 kilometers (37,500 miles).

Both Jupiter and Saturn radiate about twice the amount of energy they receive from sunlight, despite their great distances from the sun. Saturn should have cooled long ago, as it receives 100 times less sunlight than earth. Heat must therefore be generated in some other way – perhaps by interaction between the hydrogen and helium.

Even with its own heat source, Saturn is still colder than Jupiter, and material freezes at greater cloud depths. Ammonia, for example, freezes and forms clouds at a depth of two to three atmospheres on Saturn, compared to one atmosphere at Jupiter (an atmosphere is a unit of pressure corresponding to about 14.7 pounds per square inch at sea level on earth).

A considerable quantity of atmospheric dust is believed to exist, also. A high altitude haze, probably of ammonia, obscures the clouds. A belt/zone system exists similar to Jupiter's.

Visual measurements of Saturn's rotation rate give a figure of 10 hours 14 minutes for near-equatorial regions, while measurements of the pattern of Saturn's radio signals give a rate of 10 hours 39 minutes 24 seconds, more nearly akin to visual measurements at high latitudes. Precise measurement of the rate at different latitudes is important for targeting Voyager's various instruments and correlating their data. The difference in wind velocities between Saturn's equatorial and temperate zones indicates equatorial wind velocities of 1400 kilometers (900 miles) per hour – nearly twice the speed of Jupiter's winds. These wind speeds may account for the lack of long-lived atmospheric features.

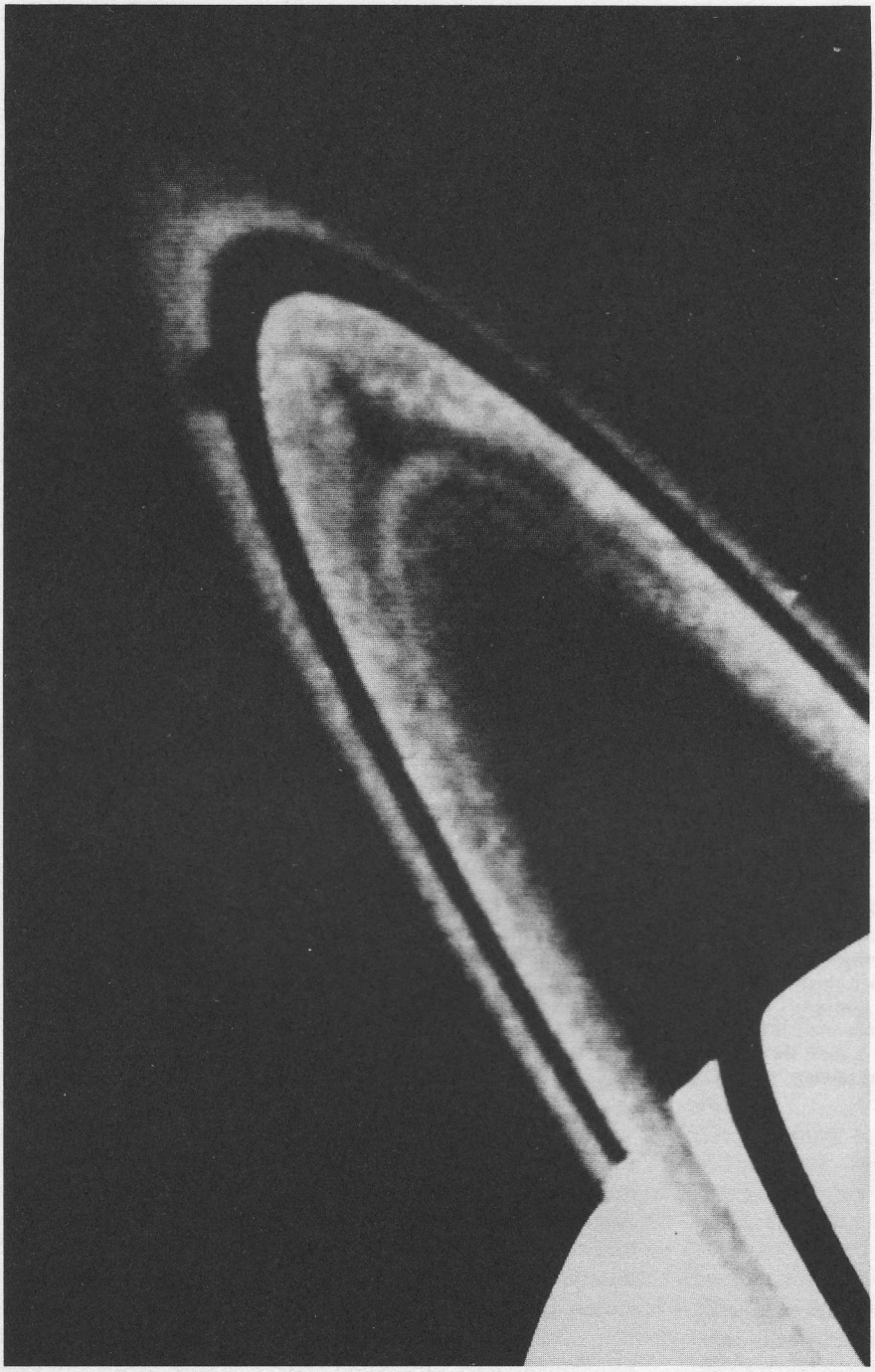
Saturn's rotation axis is inclined about 26.75 degrees from earth's orbital plane, accounting for the seeming tilt of the rings which rotate about Saturn's equatorial region. The planet's orbit is not strictly elliptical, but is affected by other planets, especially Jupiter. Wandering between 9 and 10 AU from the sun (an AU is earth's distance from the sun), Saturn makes a full trip in about 29.5 years.

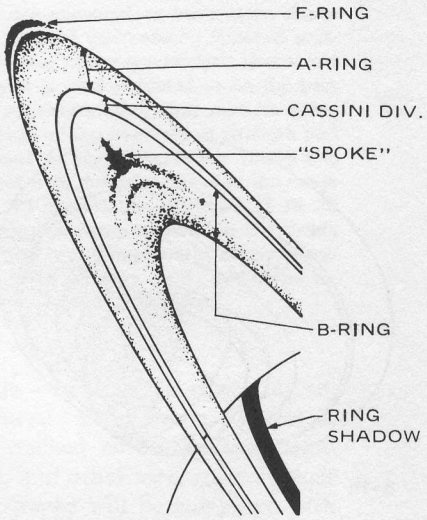
While each of Voyager's instruments operates independently, gathering specific data, analysis of Saturn is interdependent. The combined data will comprise our most comprehensive picture of the Saturn system.

At the planet, infrared spectroscopy will give information on atmospheric gas composition and abundance, clouds, hazes, temperatures, circulation, and heat balance. Ultraviolet spectroscopy will study how sunlight is absorbed and scattered in the atmosphere, to learn more about the atmospheric composition and structure. Photographs will afford a study of global wind systems and the atmospheric structure. Radio signals passing through the atmosphere will tell about the vertical structure of the atmosphere, ionosphere, clouds, and turbulence.

Voyager Bulletin

MISSION STATUS REPORT NO. 55 OCTOBER 23, 1980





SATURN'S SPOKES — New features that have never been seen before appear in this photo of Saturn's rings taken by Voyager 1 on October 5, from a distance of 51 million kilometers (32 million miles). The photo has been computer-enhanced to bring out faint details in the rings. This and similar Voyager photos are the first pictures to show irregular patterns in the rings. Visible in the B-ring is a dark, fingerlike area that rotates around the planet like a spoke in a wheel. Studies of this and similar photos reveal many similar objects; some retain their identities for several hours, despite the fact that at the inner edge of the new features, ring particles orbit Saturn once in 9-1/2 hours, while particles at the outer edge take more than an hour longer. Consequently, spokelike features like this should be erased as the inner particles "race" ahead of the outer ones. However, some features have been observed that last three or more hours. Voyager's imaging team scientists have not yet solved the question of how the spokes develop or why they remain for hours. It is unlikely that the new features are composed of groups of particles. Rather, they are more likely to be regions where there are fewer particles, reflecting less light, than other parts of the rings.

(Small, square smudged areas are reseau marks engraved on the camera, and not features of Saturn or its rings.)

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Voyager 1: Saturn Minus 20 Days
Voyager 2: Saturn Minus 306 Days

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Status Bulletin Editor (213) 354-4438
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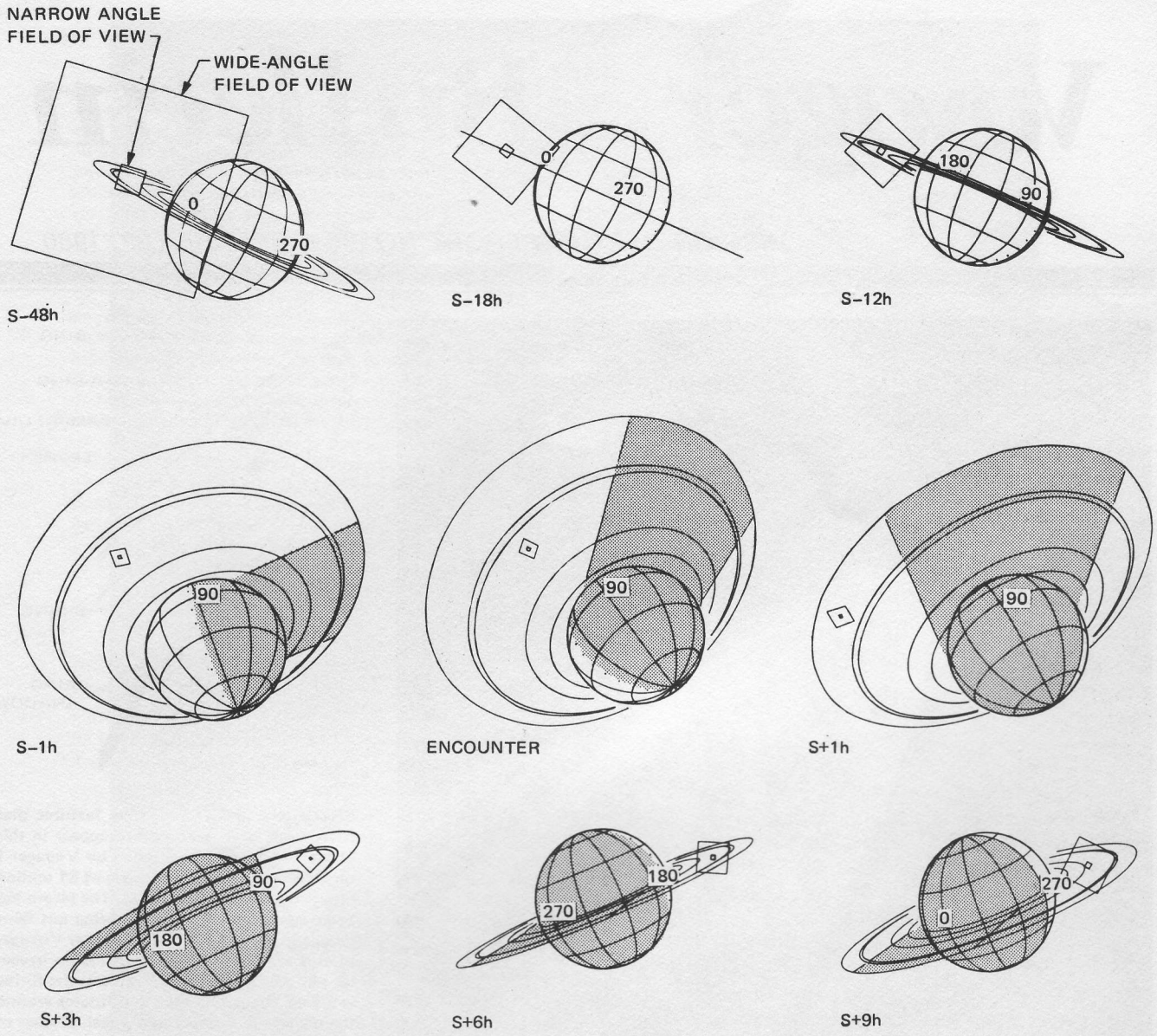


RING ASPECTS — These computer-generated plots show how Voyager 1's view of the rings will change as it flies past Saturn in November. The planet size is constant in these views to allow a comparison of Voyager's wide- and narrow-angle cameras' fields-of-view at various times (the locations of the fields-of-view shown here are not necessarily where the camera will be pointing at these times but are shown only for size comparison; the longitudes given are also for reference only). Two days before closest approach (S–48 hours), Voyager 1 will still be above the ring plane on its inbound journey. Shortly after closest approach to Titan, at about S–18 hours, the spacecraft will drop below the ring plane. Near closest approach, Voyager 1 will be above Saturn's shadowed southern hemisphere. Radio measurements of the rings will take place as the spacecraft passes behind the planet as seen from earth and all other science data will be tape recorded for about 4-1/2 hours while spacecraft telemetry is turned off. At S+4-1/2 hours, Voyager 1 will soar above the ring plane, crossing an area where the satellite Dione is thought to clear a path through the E-ring particles. Voyager 1 will continue its Saturn system observations through December 15, looking back at the receding planet.

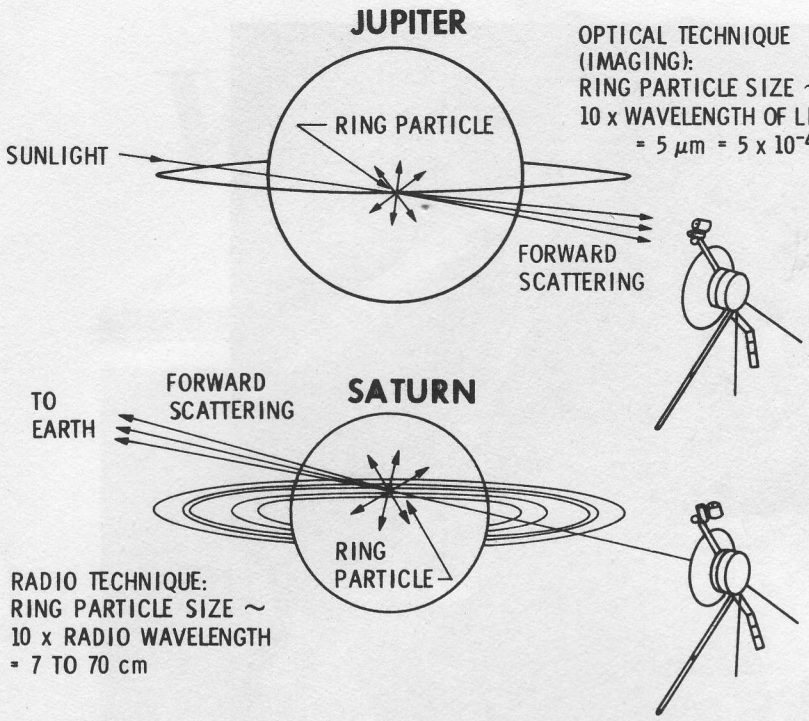
Update

Voyager 1 Enters Far Encounter Phase

On October 24, Voyager 1 will enter its next phase of Saturn observations. The narrow-angle cameras will take their last single frame images of the planet early on October 25, and then attention will be focussed on the rings for one complete planet rotation, followed immediately by images centered on Saturn for one complete rotation. For each of these sequences, narrow-angle images will be shuttered each 4.8 minutes. The rings will be photographed through the clear filter only, while all eight filters – clear (2), violet, blue, orange, green (2), and ultraviolet – will be used for the planet. These sequences will constitute the last "non-mosaicked" coverage of the planet. Regular coverage began August 22, but now one frame can no longer reliably capture the entire planet. Voyager 1 will be almost 23 million kilometers (14 million miles) and 17 days away from closest approach to Saturn when it begins the mosaics.

Once each day, the 2x2 three-color mosaics will be supplemented by three-color images on each of the two ring ansae (the outer edges of the rings), which, when combined with adjacent 2x2 mosaics, will provide 2x3 mosaics of Saturn and its rings. Infrared data will also be taken during the planet imaging.

Five narrow-angle pictures of Titan will be taken approximately every six hours. There will also be an attempt to photograph "Dione B", a tiny satellite believed



MEASURING THE RINGS – Several techniques will be used to measure the sizes of particles in Saturn's rings as the spacecraft passes behind the planet (as seen from earth). Forward scattering by ring particles is strongest when ring particles have diameters on the order of ten times the wavelength of the scattered light. The Jupiter ring, with particle diameters near 5 microns, scattered visible light effectively in a forward direction. The bulk of Saturnian ring particles are expected to have mean diameters of tens of centimeters; forward scattering of the longer-wavelength spacecraft radio signal is thus expected to be the best method of determining ring particle sizes. Attenuation of the radio signal strength and the amount of signal scattering during this period will help detect particles in the range of 7 to 70 centimeters diameter (3 to 28 inches). Optical measurements in the visible and infrared wavelengths will detect particles in the micron and millimeter-to-centimeter ranges, respectively.

to orbit at the same distance from Saturn as the intermediate-sized satellite Dione.

The ultraviolet spectrometer has been scanning the Saturn system from side to side of Titan's orbit, but now will concentrate on scans of smaller areas, gaining composition data on Saturn, Titan, the rings, and the five inner satellites. Celestial mechanics data will be extracted from the spacecraft's radio signals, while radio astronomy and plasma wave studies will continue. Several instrument calibrations will take place.

The second far encounter phase will begin November 2, ten days before closest approach. Voyager 1 will be 14 million kilometers (8.8 million miles) from Saturn.

At Saturn, Voyager will study the planet, the rings, the satellites, and the magnetosphere. Eleven science instruments fall into four broad categories: optical remote sensors, fields and particles remote sensors, fields and particles instruments, and the radio. The optical remote sensing instruments are grouped together on the scan platform perched at the edge of an 8-foot boom. These instruments – the wide- and narrow-angle cameras, the infrared interferometer/radiometer, the ultraviolet spectrometer, and the photopolarimeter – are aligned to look at about the same place so that their data may be compared. For example, the infrared instrument can provide information on the temperature of an area seen in a photograph, as it did with Io's volcanoes.

Two remote sensors measure the effects of fields and particles, studying planetary radio emissions and plasma waves. Fields and particles instruments measure magnetic fields, plasma, low-energy charged particles, and cosmic rays. These instruments also provide complementary data.

Thirdly, the spacecraft's radio signals provide essential information about atmospheric structure, planetary and satellite masses, ring particle size and density, and general relativity.

By the end of its Saturn observations in December 1980, Voyager 1 will have taken about 17,500 pictures of the Saturn system. The best resolution at the planet will be about 4 kilometers, and of some of the satellites, 2 kilometers. Many of the pictures will be mosaicked – fitted together like a jigsaw puzzle – to show an entire region. Satellite maps will be produced. Atmospheric features at Saturn and Titan will be tracked to learn about wind speeds, convection, currents, and other mechanics of their weather systems. The photographs will be compared with the infrared and ultraviolet data to produce temperature maps and compositional information.

NASA Associate Administrator Dies

Dr. Thomas A. (Tim) Mutch, NASA Associate Administrator for Space Science, was killed October 6 while leading a seven-man American team on a mountain-climbing expedition in the Himalayas.

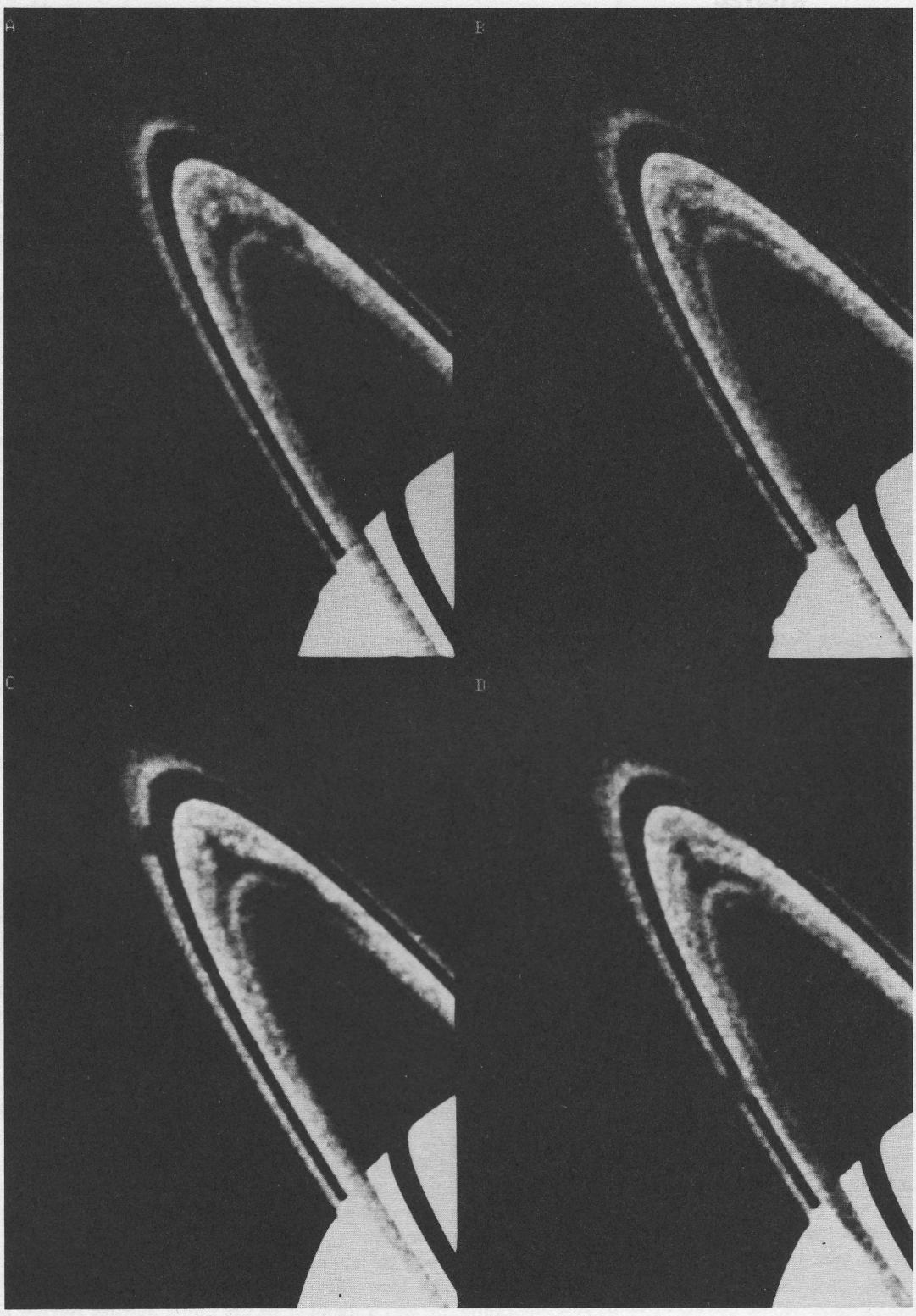
He is reported to have suffered a fatal fall on the descent from the summit of 23,410-foot Mount Nun in Kashmir, India, about 350 miles north of New Delhi.

Dr. Mutch became NASA's Associate Administrator for Space Science in 1979, and was responsible for the planning and direction of the agency's overall space science program. His enthusiasm for the space program ran high: "I feel very strongly about the space program. I feel it is vital for the nation, not just a few scientists. It's an exploration that's very much a part of our national spirit," he told an interviewer.

Prior to joining NASA, he was a professor of geology at Brown University, Providence, Rhode Island. During this time, he was a member of the Lunar Science Review Board (1969-1973), leader of the Viking Lander Imaging Science Team (1969-1977), and chairman of several NASA committees planning the post-Viking exploration of Mars. At NASA, he was involved with the Voyager and Pioneer missions.

NASA Administrator Dr. Robert A. Frosch said, "Tim Mutch was a valued friend and colleague. His contributions to the space science programs of the United States are many and earned for him an extraordinary reputation among his peers . . . His work has made significant contributions to the knowledge of our solar system"

A scholarship fund has been established at the Department of Geology, Brown University.

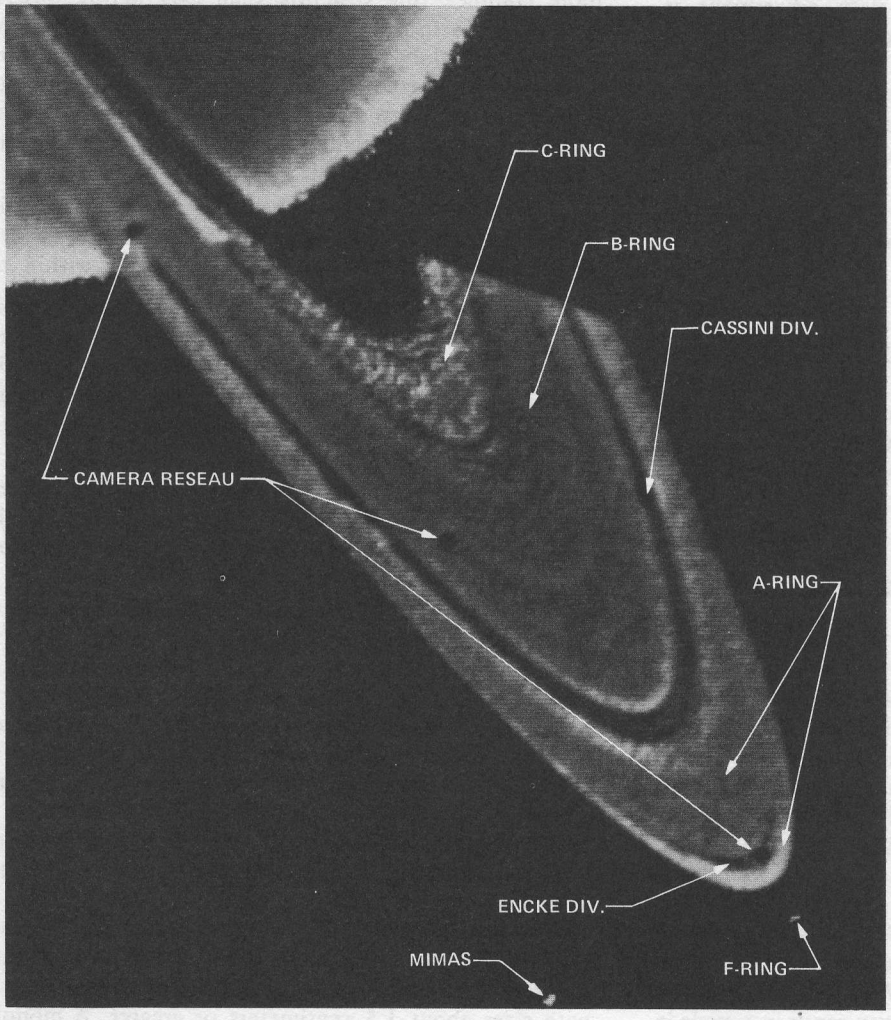


A BIG WHEEL? — Voyager 1 acquired these four photographs of Saturn's rings during a period of 12 hours on October 4 and 5, 1980. The photo at lower left is enlarged on the front page. The images have been computer-enhanced to emphasize detail in portions of the A- and B-rings, separated by the dark Cassini Division. Visible within the B-ring are patterns of dark, nearly radial features which have recently been discovered in the Voyager images. As illustrated by these examples, the shape and number of these features is quite variable. A time-lapse sequence of photographs shows that a few features retain their appearance for a period of several hours. Pre-Voyager photography has failed to show such radial structure, and most current theories predict that the rings will be uniform about their circumference, quite unlike the appearance shown here. These features probably represent regions where there are fewer particles, so that less sunlight is reflected. The origin of these variations in the density of particles is not yet understood; but they may be caused by the gravitational influence of nearby Saturn satellites.

(Small, square smudged areas are reseau marks engraved on the camera, and not features of Saturn or its rings.)

Voyager Bulletin

MISSION STATUS REPORT NO. 56 OCTOBER 31, 1980



COMPUTER-ENHANCED — Subtle color variations and new structural features in Saturn's rings can be seen in this computer composite of four Voyager 1 photos taken on October 13, 1980, 40 million kilometers (25 million miles) from the planet. The Image Processing Lab at JPL combined and enhanced the photos to make this false-color picture which exaggerates some areas. The A-ring is split by the dark Encke Division. Between the A-ring and B-ring, the Cassini Division is filled with material discovered by Voyager 1. Considerable variations in distribution and brightness of material can be seen in the B-ring. Innermost ring visible here is the C-ring, which also shows variations in distribution and brightness of material. Variations can be seen in the planet itself. The abrupt cutoff of the rings to the right is the planet's shadow on the rings.

(Three black dots in image are reseau marks, artifacts of Voyager's camera system.)

Number of Satellites Growing

Two small satellites orbiting near the F-ring have been discovered in images taken October 25. Satellite 14 orbits about 800 kilometers (500 miles) inside the F-ring (but outside the A-ring), at about 79,500 kilometers (49,000 miles) above Saturn's cloudtops. Satellite 13 orbits about 2500 kilometers (1500 miles) outside the F-ring, at about 82,000 kilometers (51,000 miles) above the clouds. Based on their apparent brightnesses, the objects are about 250 to 300 kilometers (100 to 185 miles) in diameter.

Far Encounter Part Two Begins

On November 2, Voyager 1 begins the second half of its far encounter phase. This ten-day period includes a final adjustment to the flight path, a final operational readiness test for critical radio science during near encounter, and the highest resolution three-color 3x5 mosaic of Saturn and its rings. The far encounter phases will end November 11 as the near encounter computer sequences begin.

Voyager 1 is moving away from the sun with a velocity of 20.2 kilometers per second (45,000 miles an

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Voyager 1: Saturn Minus 12 Days
Voyager 2: Saturn Minus 298 Days

Recorded Mission Status (213) 354-7237
Status Bulletin Editor (213) 354-4438
Public Information Office (213) 354-5011

hour). On November 2 it will be 14.1 million kilometers (8.8 million miles) from Saturn and 1.5 billion kilometers (949 million miles) from Earth. One-way light time – the time required for radio signals travelling at the speed of light to travel between earth and the spacecraft – is about 85 minutes.

On November 5, the radio science team and the Deep Space Network tracking stations will conduct a final operational readiness test in preparation for critical radio science experiments designed to study the atmospheres of Titan and Saturn, as well as the composition of the rings.

The last pre-encounter flight path adjustment is planned for November 6 to adjust the Titan aimpoint by about 500 kilometers.

Titan mosaics will begin early on November 11, 16 hours before closest approach to this satellite.

Celestial mechanics experiments, fields and particles measurements, and satellite searches will continue during this phase. Voyager 1 is expected to enter Saturn's magnetosphere sometime between November 9 - 12.

Press Activities

Voyager Project Manager Ray Heacock and Project Scientist Ed Stone of Caltech briefed NASA Administrator Dr. Robert Frosch and Presidential Science Advisor Frank Press in Washington, D.C., on October 27. The first Voyager Saturn press conference was held in Washington on October 28. Daily press conferences are planned in JPL's von Karman Auditorium November 6 through 15. Television broadcasts from JPL will be beamed around the world via SATCOM on November 11, 12, and 13.

SATURN's RINGS

Glimmering, glistening, beckoning, Saturn's rings are like the mythological Sirens – enticing, mysterious, confounding. Man has puzzled over their nature since Galileo first observed them in 1610. He first announced that Saturn was a triple planet having two small satellites rapidly and closely revolving around the bigger planet. Imagine his consternation when, in 1612, all traces of these small globes were gone!

Today we know that Galileo's globes are really a broad system of rings rotating around the planet's equator. Saturn's equatorial plane is tipped 27° to its orbital plane. The orbital motions of earth and Saturn result in a cycle in which earth is above the ring plane for about 15 years, and then below the plane for about 15 years. At the time of ring-plane passage, the rings appear edge-on to an earth-based observer, and hence, with simple viewing equipment like Galileo used, seem to disappear. Earth's upward ring plane crossing in March 1980 afforded astronomers the most recent opportunity to view the edge-on rings.

Voyager 1 will cross the ring plane twice – once inbound and once outbound. Now approaching from above the ring plane, Voyager 1 will dip below the ring plane about 18 hours before closest approach to the planet. Twenty-four hours later, the spacecraft will rise above the ring plane on an upward path which will send it 35° above the ecliptic (the plane in which most of our solar system orbits the sun) and 26° above Saturn's equatorial plane. On its outbound passage, Voyager 1 will fly through the E-ring, which is thought to be of rather low density and therefore harmless to the spacecraft. Just in case, however, Voyager 1's scan platform instruments will face in a direction such that no ring particles will pit optical surfaces.

The rings have been named in the order of their discovery; therefore, the labels do not indicate their relative positions. The A- and B-rings were discovered together. From the planet outward, they are designated the D (which may not exist), C, B, A, F, and E rings. Even now, however, it is obvious that the International Astronomical Union has its work cut out settling upon a nomenclature for the myriad concentric rings and other structure now being seen in Voyager photographs.

Divisions between the rings have been obvious since the 1600's, but Voyager's pictures are showing a much more complex ring structure than ever before observed. New divisions in the B- and C-rings are obvious, and more will most certainly be found before the end of Voyager 1's observations. Current theory supposes that gravitational effects from Saturn's satellites controlled the orbits of particles around the planet, but new mechanisms governing ring motions may be found.

The Cassini Division between the A and B rings, approximately 4000 kilometers (2500 miles) wide, is actually filled with material, and has divisions within itself.

Dark, radial features in the B-ring are puzzling since the ring particles rotate at different speeds. Theoretically, such features should never form, or at least be short-lived, since the outer potion of the rings rotates slower than the inner portion. But some of these features have observed lifetimes as long as three hours.

On October 25, the rings were photographed every 4.8 minutes for ten hours. When processed into a time-lapse movie, these pictures may show the radial features forming and dissipating. Density waves may also be visible.

What is the ring composition? Water ice in the rings was first identified in 1970; however, the variation in light reflected from the rings indicates that they are not pure water ice. Results from Pioneer 11 indicate that the ring reflectivity more resembles that of Jupiter's satellite Io – there is a reddening effect which could be due to trace impurities or to charged particle bombardment on an ice lattice.

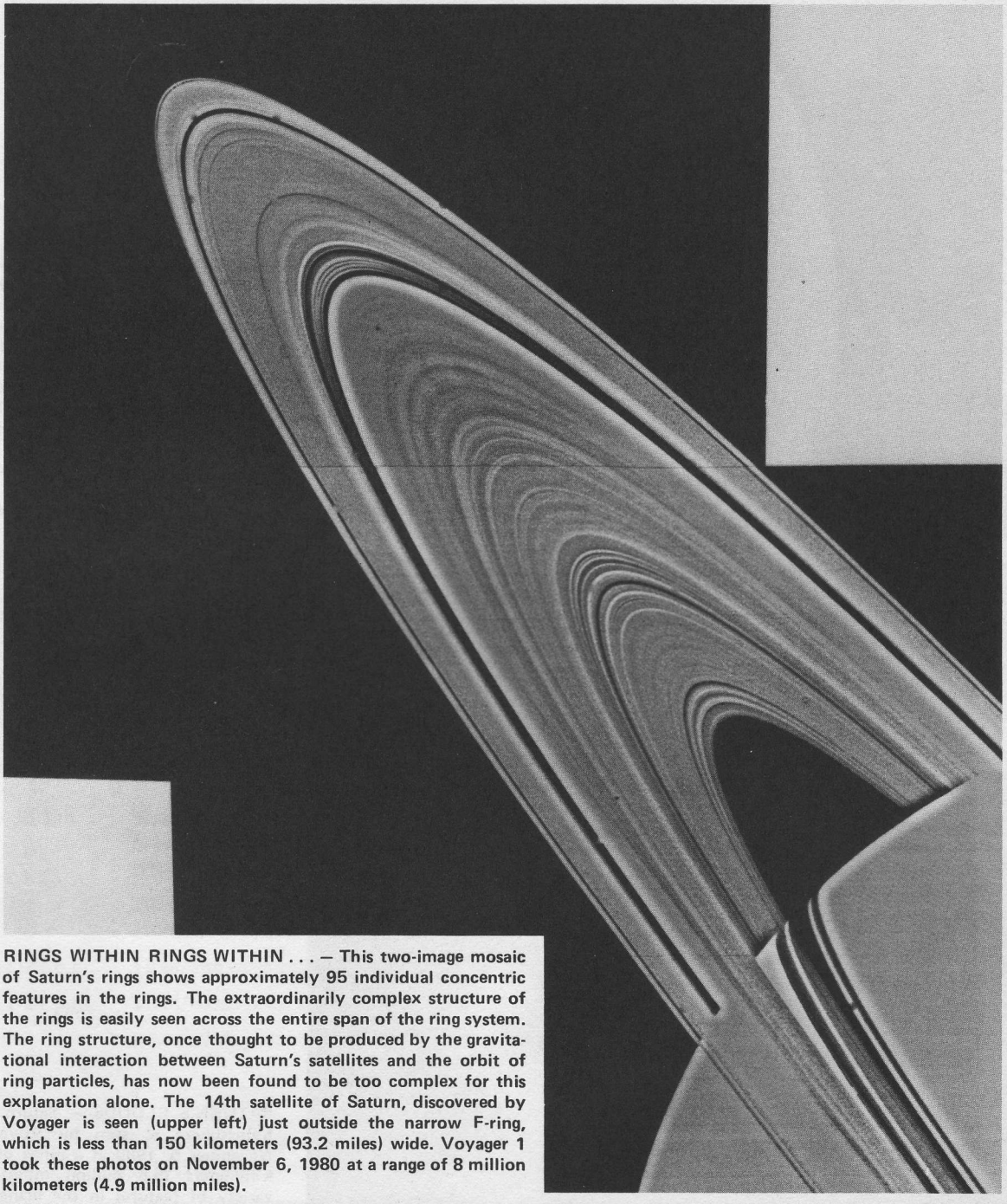
How thick are the rings? The E-ring may be as thick as 1800 kilometers (1100 miles) – the driving distance from Los Angeles to Denver. Earth-based observations indicate that the visible rings may be just a few kilometers thick, if the particle sizes are less than 15 meters. Current theories favor multiple layers of ice or ice-covered rock with sizes about 1.5 centimeters or greater. A monolayer seems improbable partially because of previously-measured temperature differences between the lit and unlit sides of the rings. Voyager's infrared instrument will take the rings' temperature from both sides, several angles, and in the planet's shadow to help determine particle sizes. Radio experiments will also measure thicknesses, sizes, density, and composition of the rings.

How did the rings form? There are two major theories of ring formation: 1) through tidal breakup of a pre-existing comet or satellite, or 2) as a remnant of the proto-planetary nebula from which the planet itself formed. Findings on the particle size distribution and bulk composition should give an answer to this tantalizing question.

Pioneer 11 also found that Saturn's rings form an umbrella under which the radiation intensity drops dramatically. This region, in fact, was the most benign space through which Pioneer has travelled in its entire seven years of exploration. Saturn's radiation, therefore, is not expected to pose any threat to the Voyager spacecraft as they fly under the rings.

Voyager Bulletin

MISSION STATUS REPORT NO. 57 NOVEMBER 7, 1980



RINGS WITHIN RINGS WITHIN . . . — This two-image mosaic of Saturn's rings shows approximately 95 individual concentric features in the rings. The extraordinarily complex structure of the rings is easily seen across the entire span of the ring system. The ring structure, once thought to be produced by the gravitational interaction between Saturn's satellites and the orbit of ring particles, has now been found to be too complex for this explanation alone. The 14th satellite of Saturn, discovered by Voyager is seen (upper left) just outside the narrow F-ring, which is less than 150 kilometers (93.2 miles) wide. Voyager 1 took these photos on November 6, 1980 at a range of 8 million kilometers (4.9 million miles).

NASA

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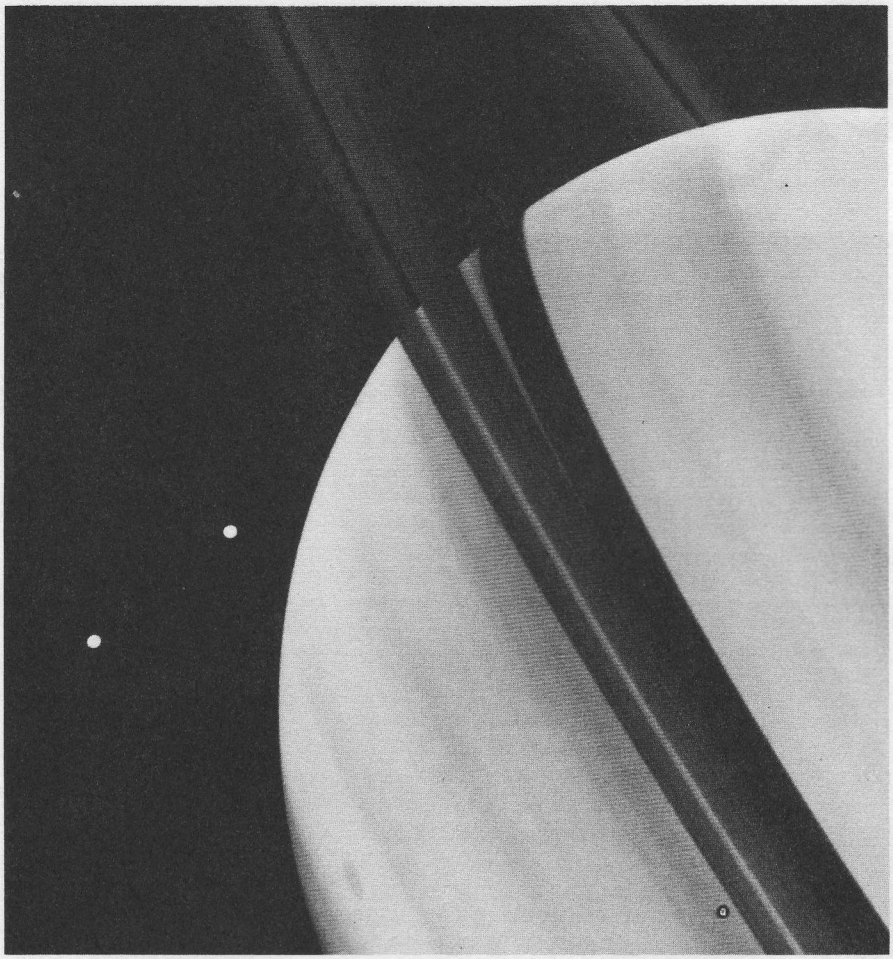
Voyager 1: Saturn Minus 5 Days
Voyager 2: Saturn Minus 291 Days

Recorded Mission Status (213) 354-7237
Status Bulletin Editor (213) 354-4438
Public Information Office (213) 354-5011

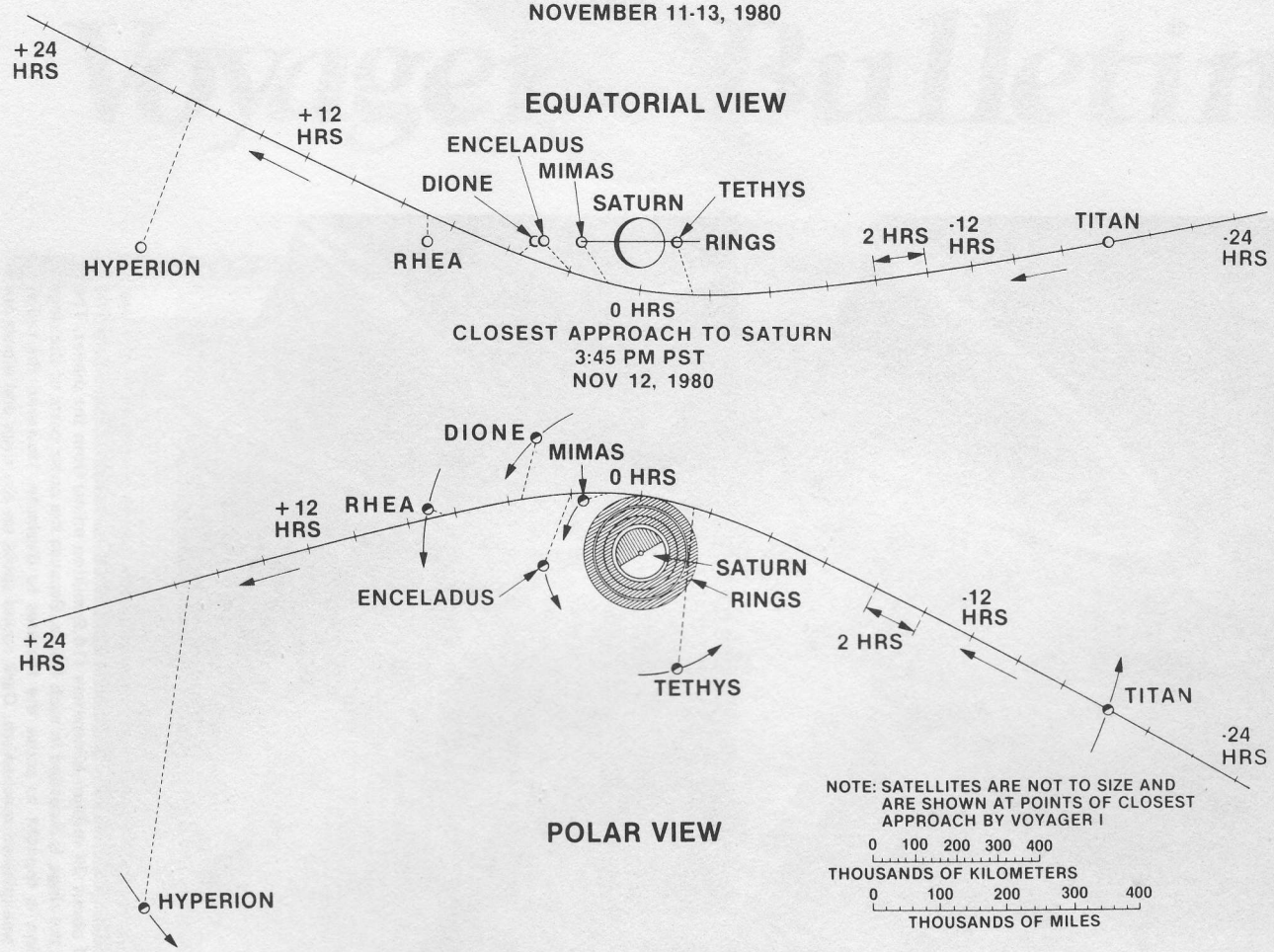


CLOSING IN – Saturn, its rings, and two of its moons, Tethys (above) and Dione, were photographed by Voyager 1 on November 3, 1980, from 13 million kilometers (8 million miles). The shadows of Saturn's three bright rings and Tethys are cast onto the cloud tops. The limb of the planet can be seen easily through the 3500-kilometer-wide (2170 miles) Cassini Division, which separates Ring A from Ring B. The view through the much narrower Encke Division, near the outer edge of Ring A, is less clear. Beyond the Encke Division (at left) is the outer edge of the A-ring.

SATURN'S CLOUDS – Saturn's northern hemisphere as seen by Voyager 1 on November 5, 1980 at a range of 9 million kilometers (5.5 million miles) shows a variety of features in the planet's clouds: Small-scale convective cloud features are visible in the dark belt (center); an isolated convective cloud with a dark ring is seen in the lighter zone; and a longitudinal wave is visible in the brighter zone (right of center belt). The smallest features visible in this photograph are 175 kilometers (108.7 miles) across.

TWO VIEWS OF VOYAGER I FLYBY OF SATURN

NOVEMBER 11-13, 1980



Encounter Highlights

All times are Pacific Standard Earth-received time of event. All distances are from surfaces of satellites except where noted.

November 11

9:52 – 10:36 a.m.	Spacecraft maneuver to sample fields and particles near Saturn; reference star is Miaplacidus
11:05 p.m.	Titan closest approach (4000 kilometers)
11:11 – 11:22 p.m.	Titan/Sun occultation
11:12 – 11:24 p.m.	Titan/Earth occultation
11:22 p.m.	Inbound ring plane crossing

November 12

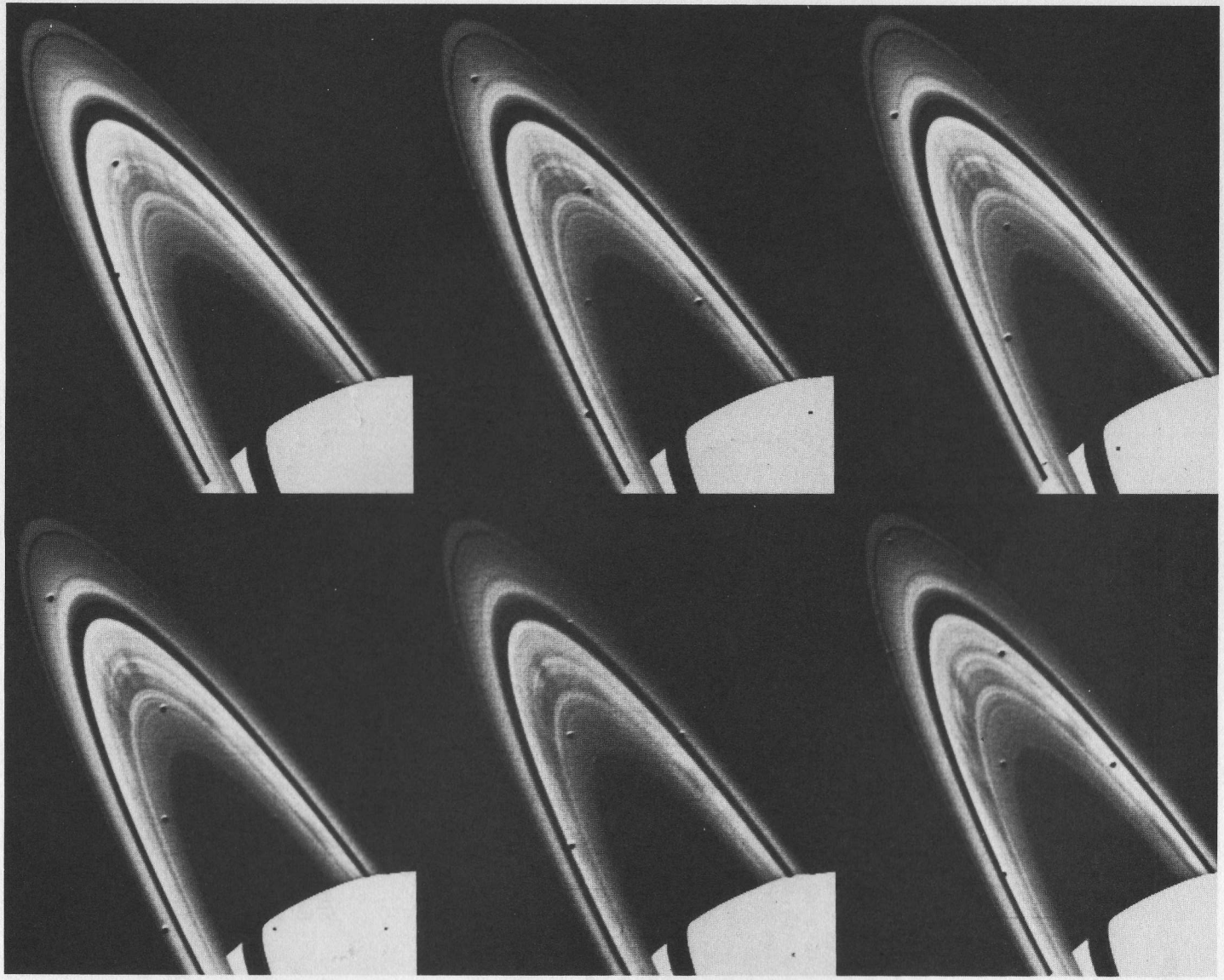
3:41 p.m.	Tethys closest approach (415,320 kilometers)
5:10 p.m.	Saturn closest approach (124,200 kilometers above clouds)
7:07 p.m.	Mimas closest approach (88,820 kilometers)
7:15 p.m.	Enceladus closest approach (202,251 kilometers)
6:09 – 6:33 p.m.	Spacecraft maneuver to sample fields and particles
7:08 – 8:35 p.m.	Saturn/Earth occultation
7:22 – 8:02 p.m.	Saturn/Sun occultation
9:03 p.m.	Dione closest approach (161,131 kilometers)
8:44 – 9:00 p.m.	Ring/Earth occultation
9:45 p.m.	Outbound ring plane crossing
11:46 p.m.	Rhea closest approach (72,000 kilometers)
11:09 – 11:26 p.m.	Spacecraft maneuver to sample fields and particles; reference star is Alhena
11:38 p.m. – 12:41 a.m.	Rhea image motion compensation maneuver; reference star is Vega

November 13

10:09 a.m.	Hyperion closest approach (879,127 kilometers)
2:42 – 4:43 p.m.	Spacecraft maneuver; return to Vega

November 14

12:50 a.m.	Iapetus closest approach (2,474,000 kilometers)

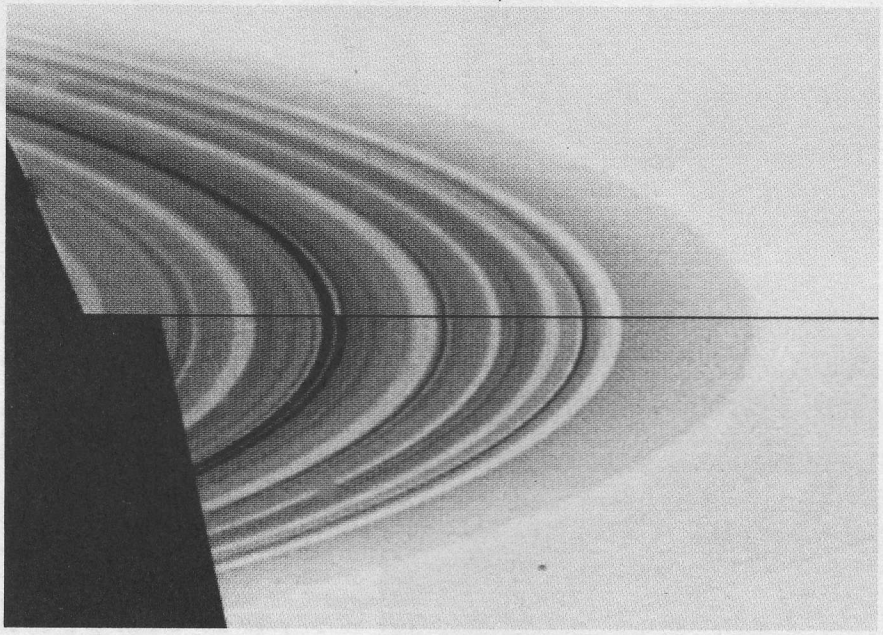


FEATURES IN SATURN'S RINGS — Dark spokelike features in Saturn's B-ring are seen revolving around the planet with the rings' orbital motion in these six photographs taken by Voyager 1 on October 15, 1980. The images were taken in sequence (from upper left to lower right) approximately every 15 minutes at a distance of about 24 million kilometers (14.9 million miles) from the planet. The rotation of the spokelike features, visible in the brightest part of the rings, is recorded in each frame. Because the outer parts of the rings revolve more slowly than the inner rings, the differential motion is thought to cause the features to dissipate. However, the radial features are apparently ubiguitous and are regenerated by some unexplained mechanism. Dark round spots on the rings and planet are reseau marks engraved on the camera and are not features of Saturn.

Voyager Bulletin

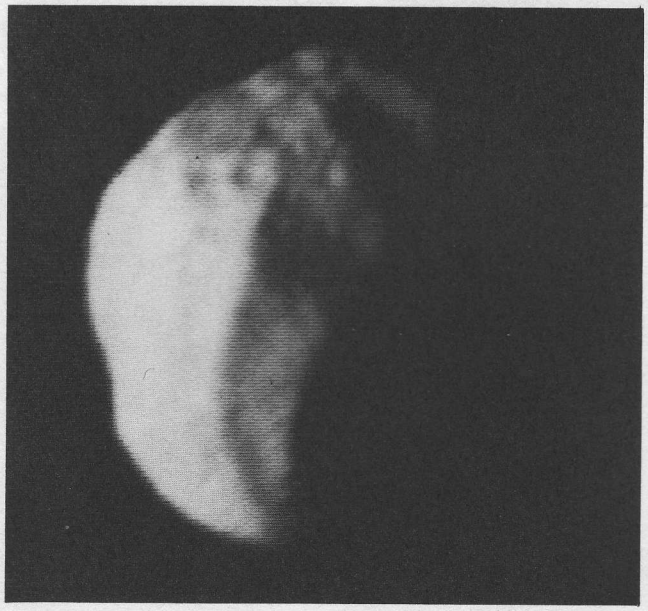
MISSION STATUS REPORT NO. 58 NOVEMBER 16, 1980

Voyager 1 11/10/80 3,000,000 km (2,000,000 mi)



ECCENTRIC RING – An "out-of-round" or eccentric ring identified in Voyager 1 photos of the C-ring is seen in the dark gap in the center of this high resolution composite photo. The bright ring is narrowed in the lower picture and slightly broadened and displaced within the gap in the upper picture. The horizontal line through the center marks the border between the two photos; at top the trailing ansa of the rings, and bottom the leading ansa.

Voyager 1 11/12/80 177,000 km (110,000 mi)



A CO-ORBITAL – A ring shadow crosses the south polar region of Saturn's eleventh moon, a trailing co-orbital satellite. Comparison of the two images, taken 13 minutes apart, reveals a narrow shadow moving across its face. The shadow is probably cast by a small, narrow ring of Saturn a few thousand kilometers away from the satellite. The pock-marked moon is approximately 135 by 70 kilometers (80 by 40 miles).

NASA
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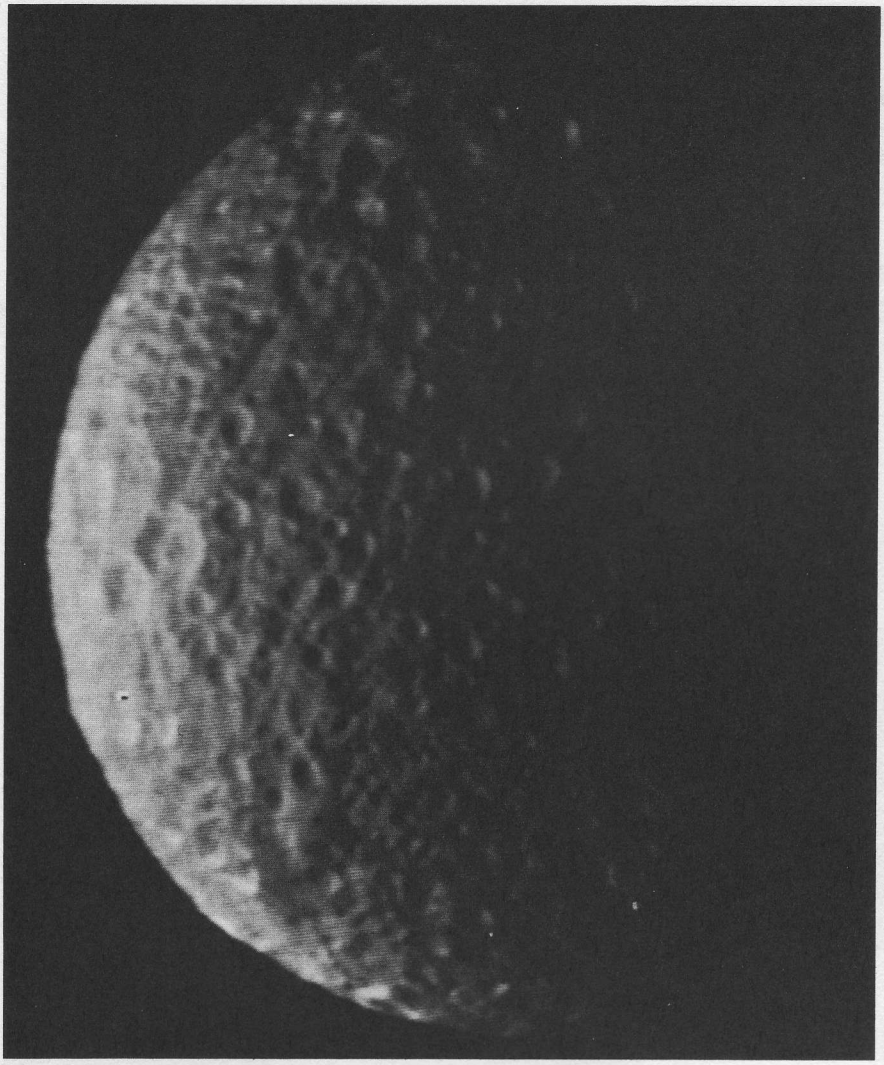
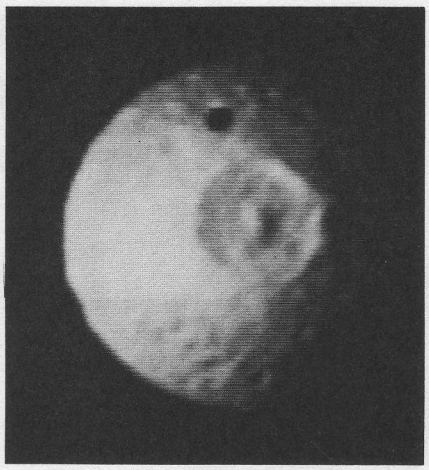
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Voyager 1: Saturn Plus 4 Days
Voyager 2: Saturn Plus 282 Days

Recorded Mission Status (213) 354-7237
Status Bulletin Editor (213) 354-4438
Public Information Office (213) 354-5011

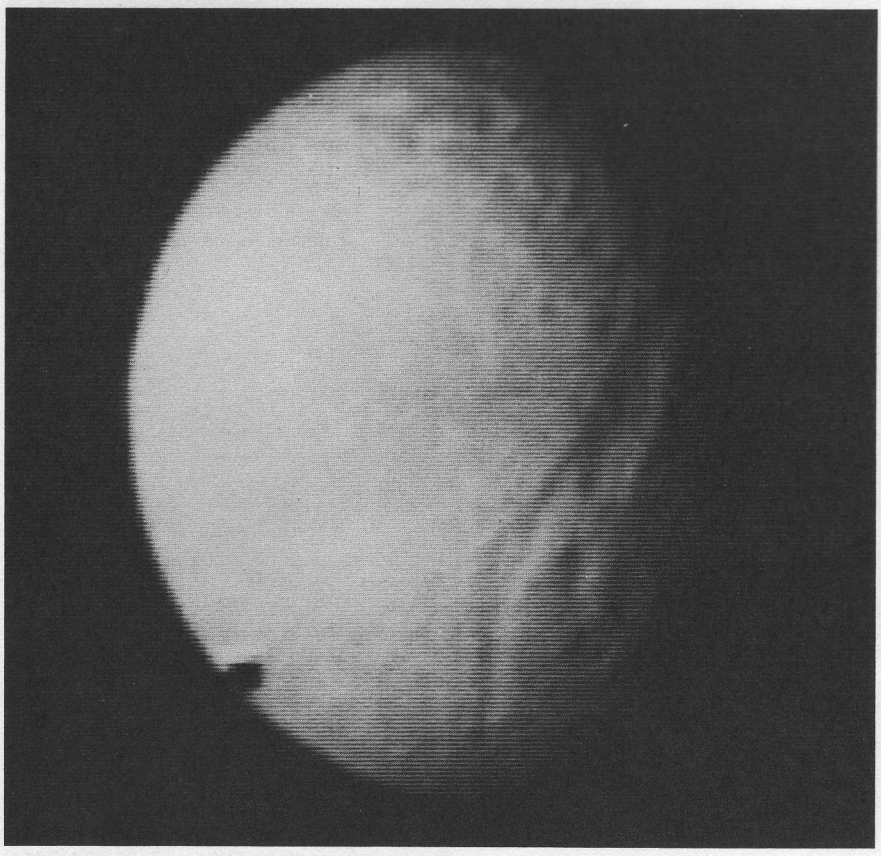


Voyager 1 11/12/80 129,000 km (80,000 mi)



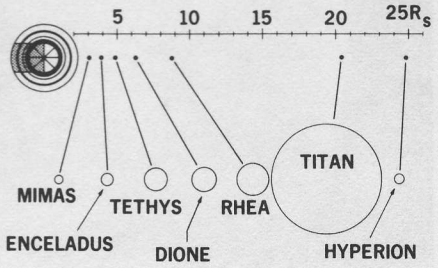
Voyager 1 11/12/80 660,000 km (400,000 mi)

MIMAS – On its inbound path, Voyager 1 saw a large impact crater (above) on the leading face of Mimas, at about 110° W. longitude. (The dark spot above the crater is a camera reseau.) This structure may give Mimas the largest ratio of satellite diameter to crater diameter in the solar system, for the crater's size – 130 kilometers (80 miles) diameter – is one fourth that of the entire satellite. At left, a closer view of another face of Mimas records a period of heavy meteorite bombardment that occurred some four billion years ago. Craters as small as two kilometers (one mile) across can be seen on the 385-kilometer (240-mile) diameter moon in this photo.

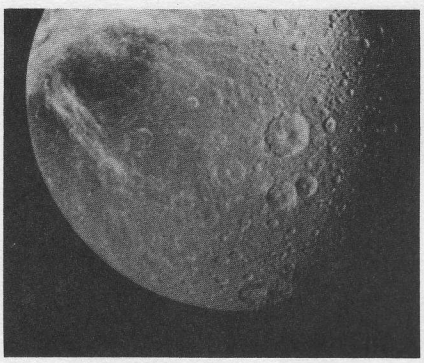


Voyager 1 11/12/80 1,200,000 km (750,000 mi)

VIEW FROM SATURN'S NORTH POLE

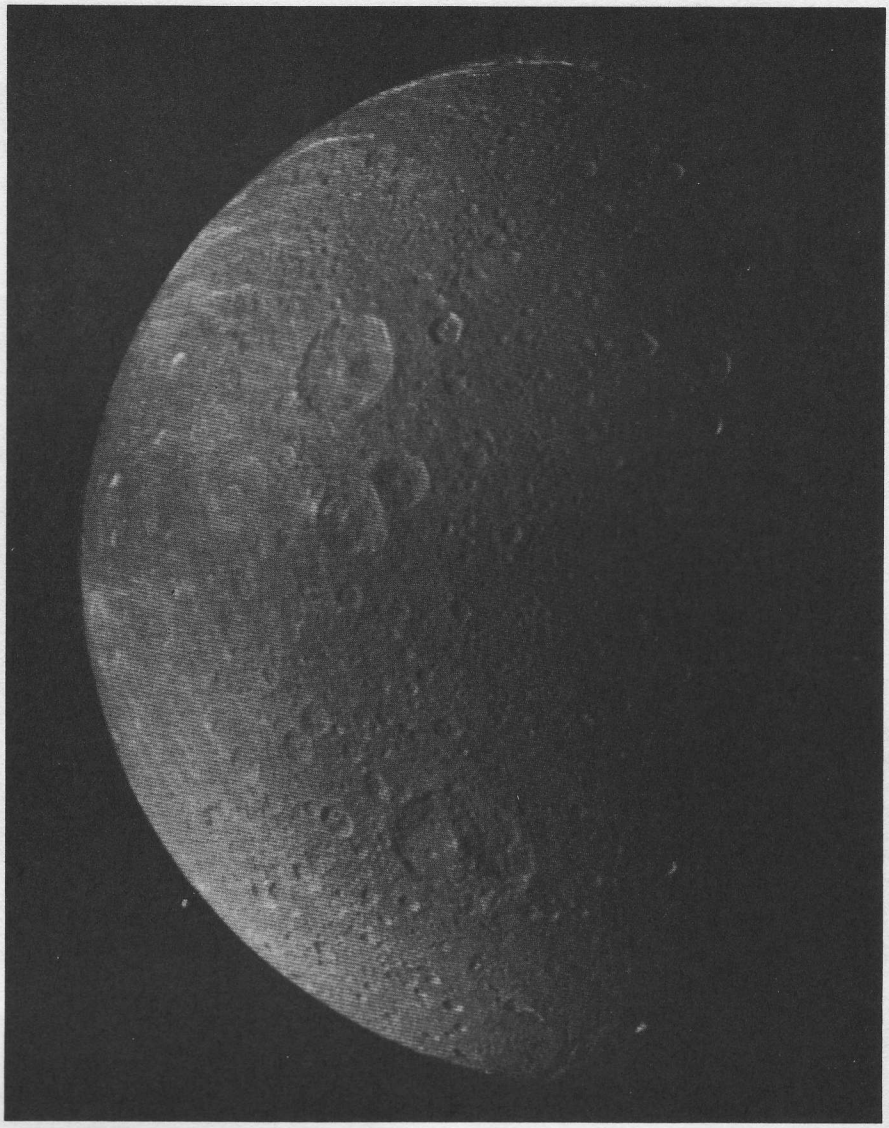


TETHYS – The heavily cratered surface of this face of Tethys looks toward Saturn and shows a large valley about 750 kilometers long and 60 kilometers wide (500 by 40 miles). The craters are probably the result of impacts and the valley appears to be a large fracture of unknown origin. Tethys is slightly less than one-third the size of Earth's Moon. The smallest feature visible on this picture is about 24 kilometers across.



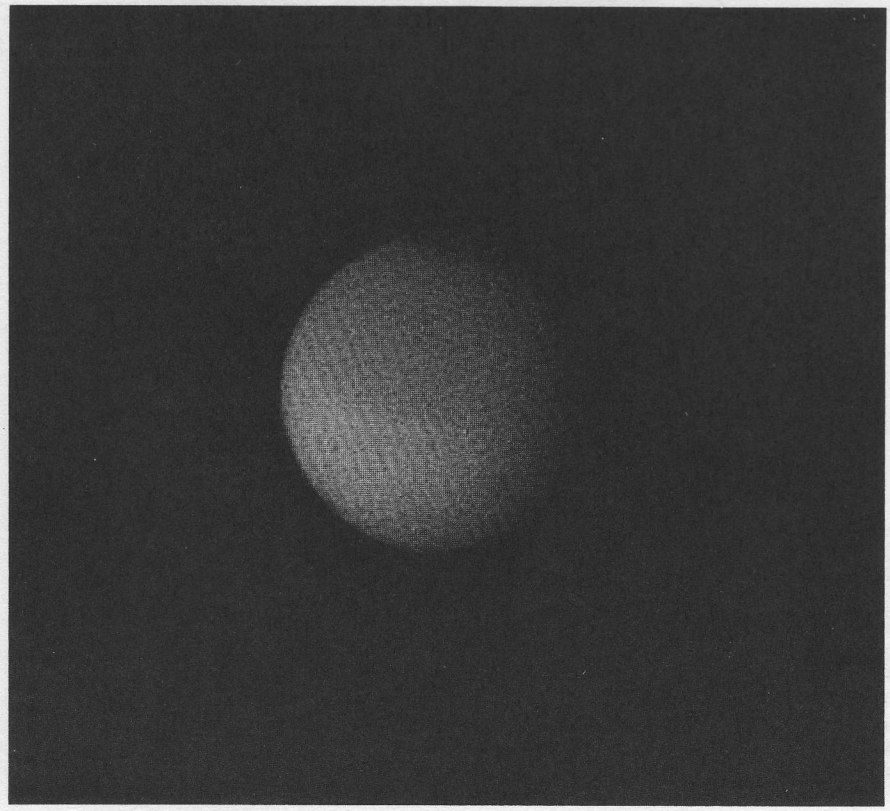
Voyager 1 11/12/80

240,000 km (149,000 mi)



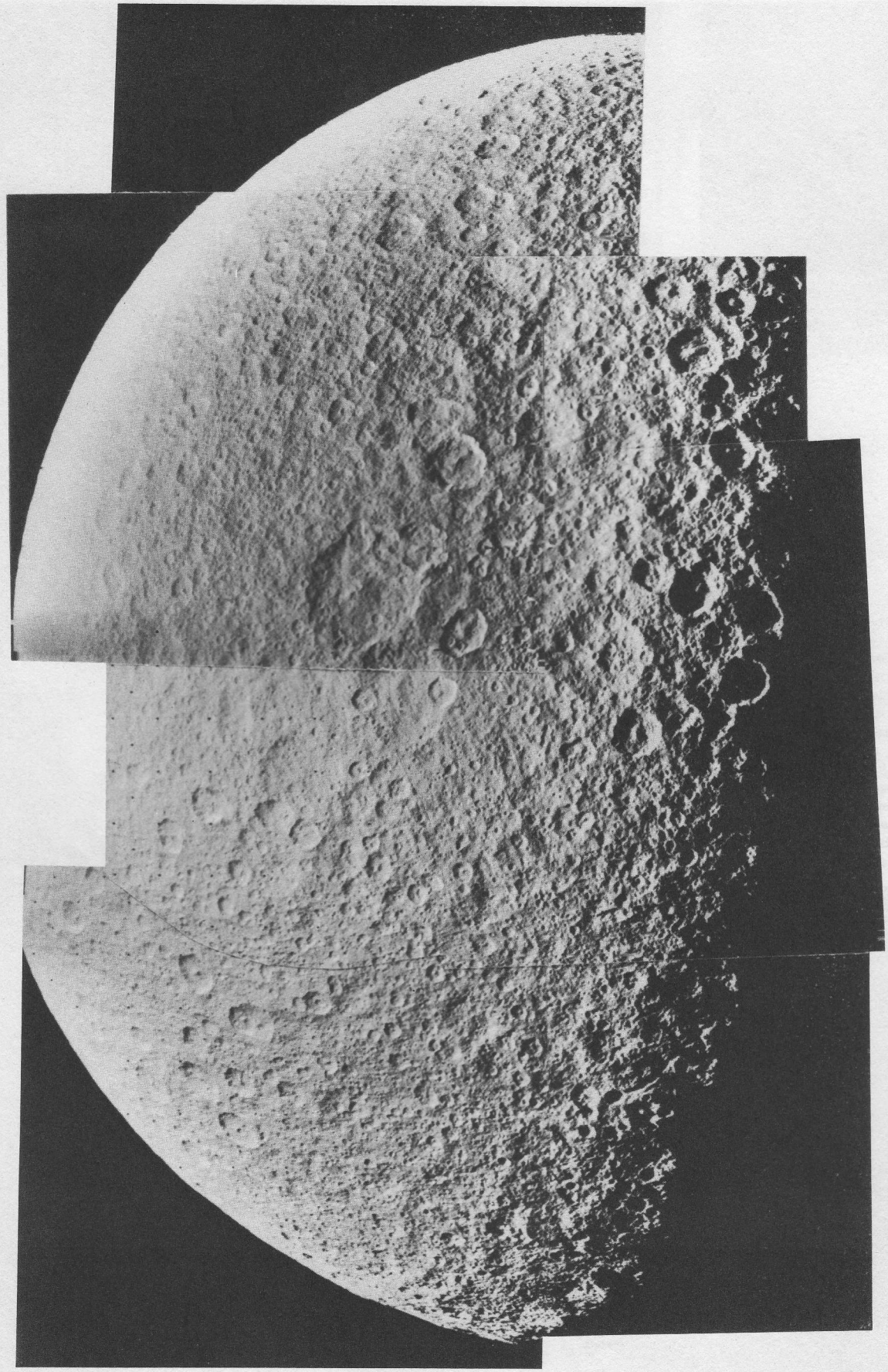
Voyager 1 11/12/80 162,000 km (100,600 mi)

DIONE — Circular impact craters up to about 100 kilometers (60 miles) diameter and bright wispy markings delineate the surface of Dione (top). The wispy structures may be surface frost deposits, possibly due to internal geologic activity. The trailing face of Dione (mosaic at right) also shows many impact craters — the record of the collision of cosmic debris. The largest crater is less than 100 kilometers (60 miles) in diameter and shows a well-developed peak. Bright rays represent material ejected from other impact craters, while sinuous valleys probably formed by crustal fractures break the moon's icy crust.



Voyager 1 11/9/80 4,509,000 km (2,800,000 mi)

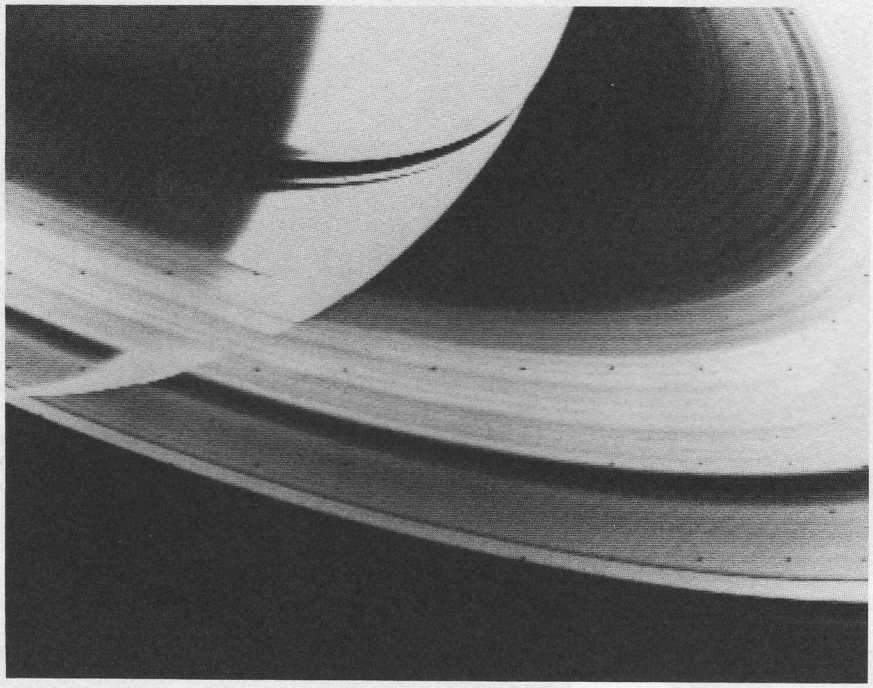
TITAN HAZE — A thick atmospheric haze above the cloud level shrouds Titan, Saturn's largest satellite. A dark polar hood, and a darker northern hemisphere are seen in this inbound view. The divisions in the haze occur at altitudes of 200, 375 and 500 kilometers (124, 233 and 310 miles) above the limb of the moon.



RHEA — Craters stand shoulder-to-shoulder on the surface of Saturn's satellite Rhea, seen in this mosaic of the highest-resolution pictures of the north polar region of the moon. Rhea is 2,400 kilometers (1,490 miles) in diameter and is the most heavily cratered of the moons of Saturn. The largest crater, made by the impact of cosmic debris, is about 300 kilometers (185 miles) in diameter. Many craters have central peaks formed by the rebound of the floor after the explosive formation of the crater. Multiple ridges and grooves visible near the shadow edge resemble those seen on Earth's Moon and Mercury.

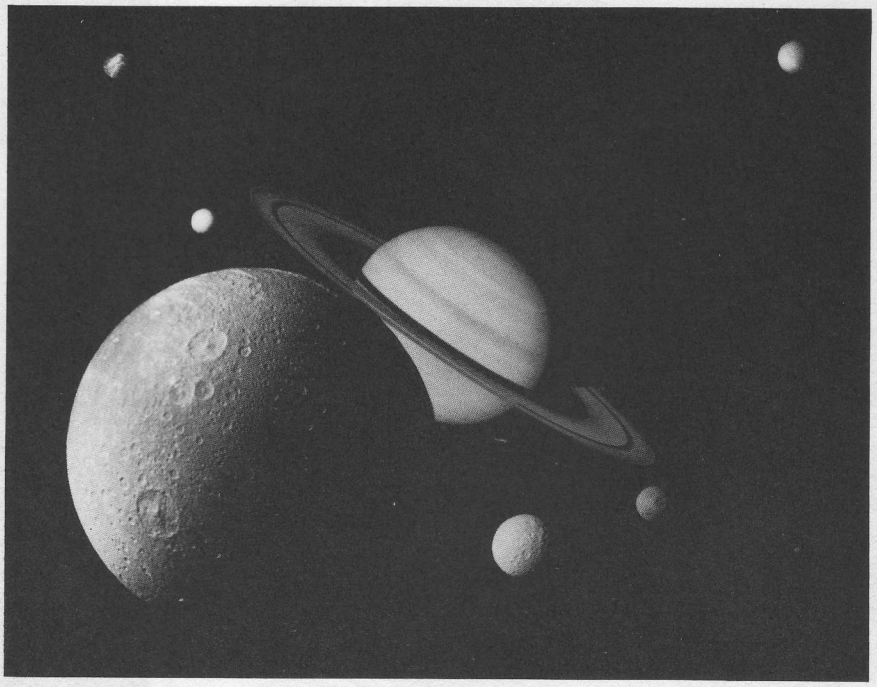
Voyager Bulletin

MISSION STATUS REPORT NO. 59 NOVEMBER 21, 1980



Voyager 1 11/13/80 1,500,000 km (930,000 mi)

PARTING SHOT — Looking strangely serene, the crescent of Saturn, the planet's rings and their shadows are seen in this image as Voyager 1 began to leave the Saturn system. The bright limb of Saturn is clearly visible through the A, B, and C rings, while the dark band cutting through the crescent is the shadow of the rings. The crescent appears artificially brighter since this image was overexposed to bring out detail in the rings.



Voyager 1 11/17/80

SATURN SYSTEM — This montage of images was prepared from an assemblage of images taken by Voyager 1 during its Saturn encounter in November 1980. This artist's view shows Dione in the forefront, Saturn rising behind, Enceladus and Rhea off Saturn's rings to the lower right, Tethys and Mimas fading in the distance to the upper left, and Titan in its distant orbit at the top.

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Voyager 1: Saturn Plus 9 Days
Voyager 2: Saturn Minus 277 Days

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Status Bulletin Editor (213) 354-4438
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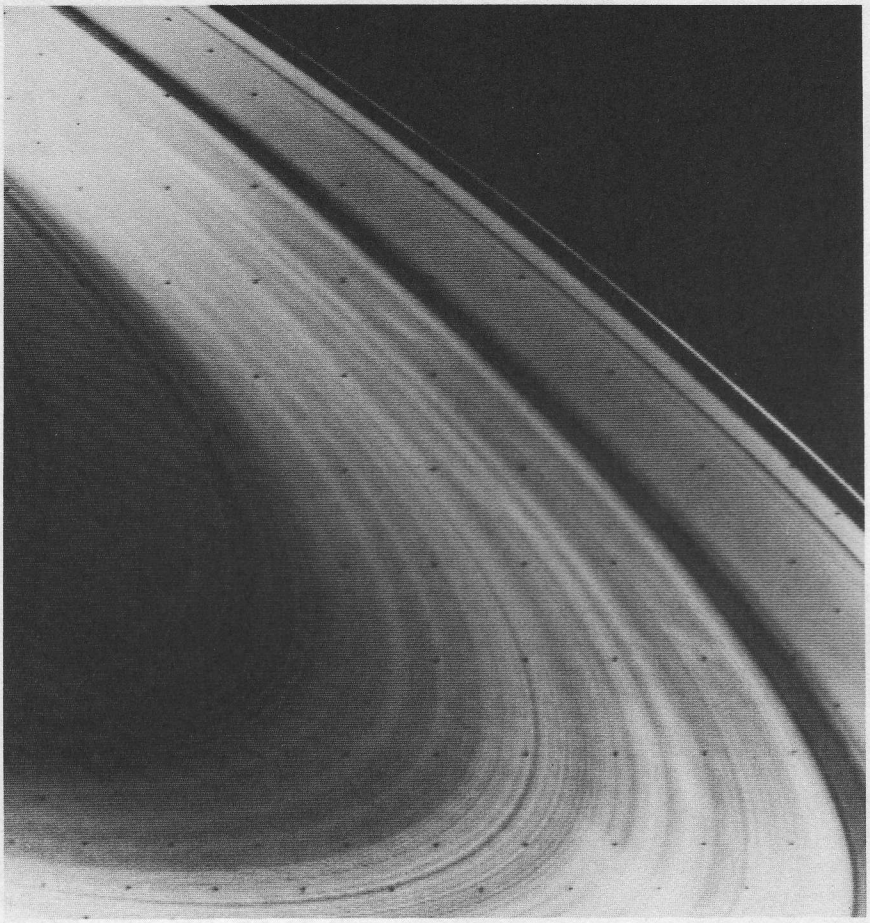
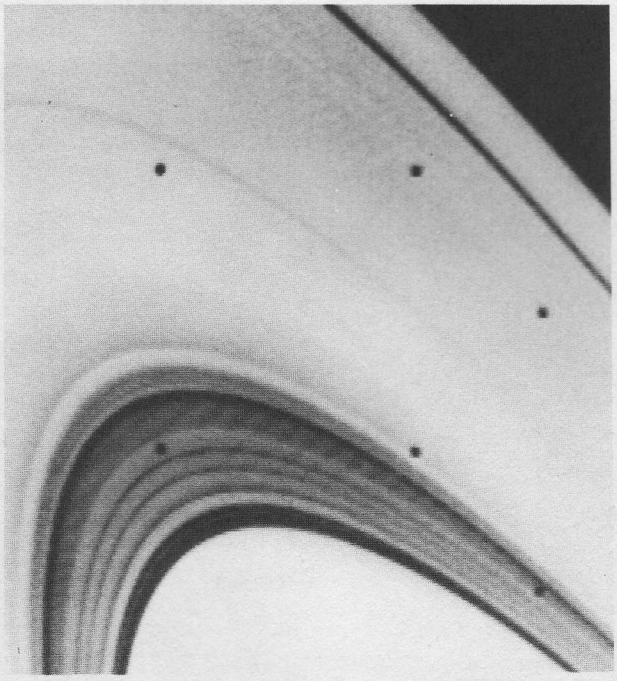


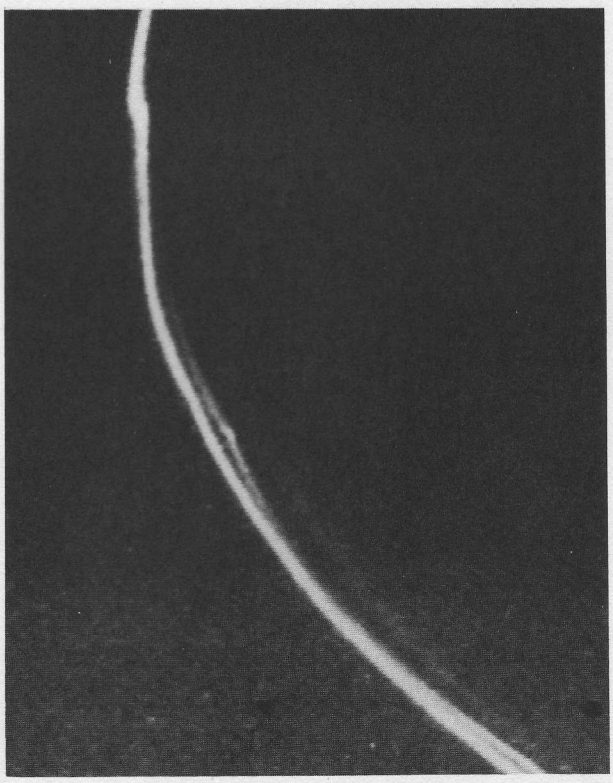
Voyager 1 11/12/80 720,000 km (446,000 mi)

OUTBOUND – Voyager 1 gave us this view of Saturn's rings from above, eight hours after its closest approach to the planet. The unique lighting highlights the many hundreds of bright and dark ringlets comprising the ring system. The C-ring (dark gray area) seems to blend into the brighter B-ring as the concentric features radiate out from the planet. The dark spoke-like features seen in images taken during the approach to Saturn now appear as bright streaks, indicating that they possess a strong forward-scattering property, and may be smaller particles preferentially separated from larger particles, perhaps by static electricity along the magnetic field lines passing through the B-ring.



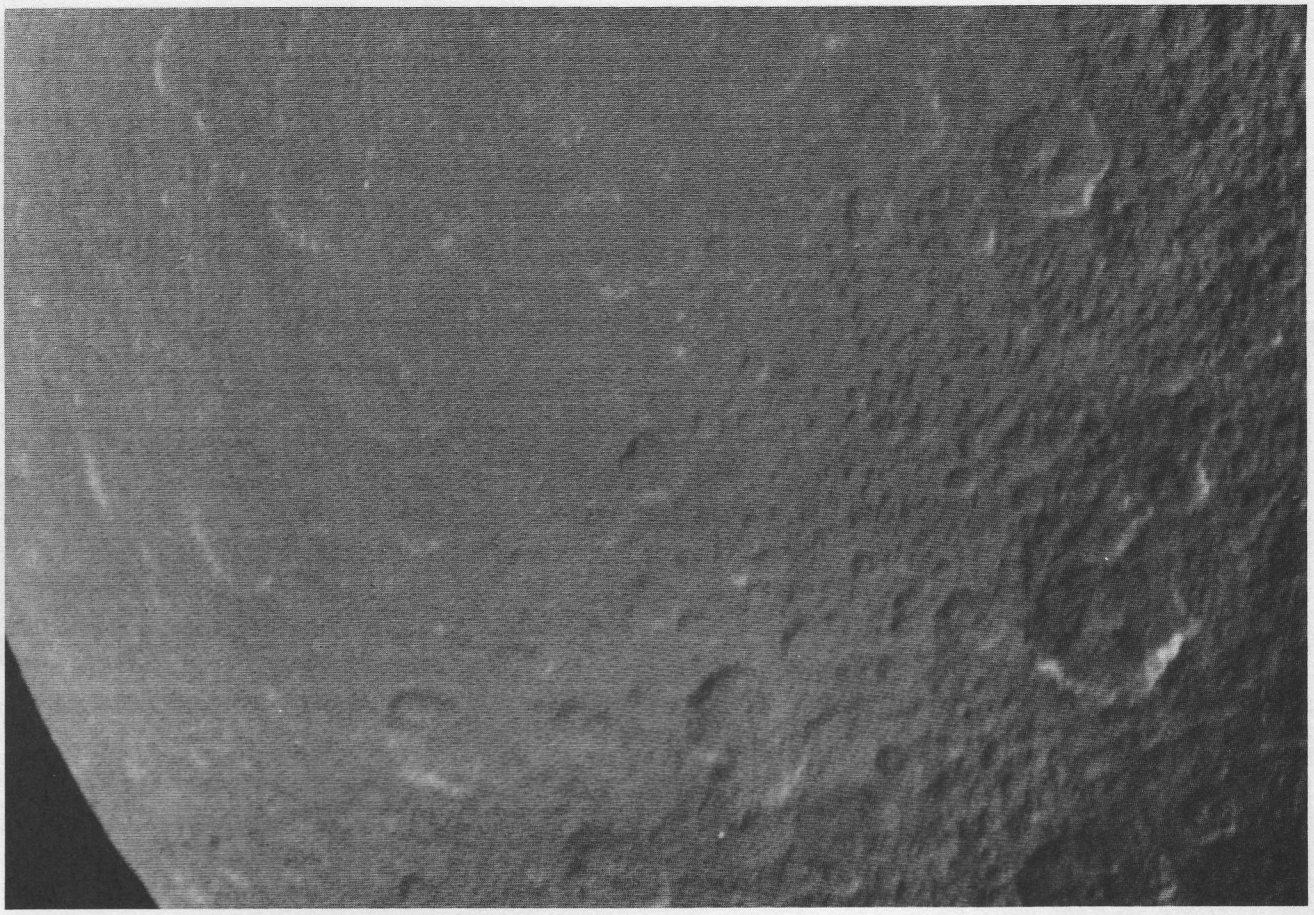
Voyager 1 11/8/80 6,000,000 km (4,000,000 mi)

FAR FROM EMPTY – Once believed devoid of material, the Cassini Division may be filled with over 20 ringlets of its own. Discovered by Cassini in 1675, the Division is a 3500-kilometer (2200-mile) stretch between the classical A- and B-rings (the region between the two dark ringlets). A number of individual features (from its outer boundary to the inner boundary) are visible here: a medium dark ringlet, 800 kilometers (500 miles) wide; four brighter ringlets, approximately 500 kilometers (300 miles) wide and separated by dark divisions; and a new, barely visible, narrow (about 100 kilometers or 50 miles), bright ringlet at the inner boundary.



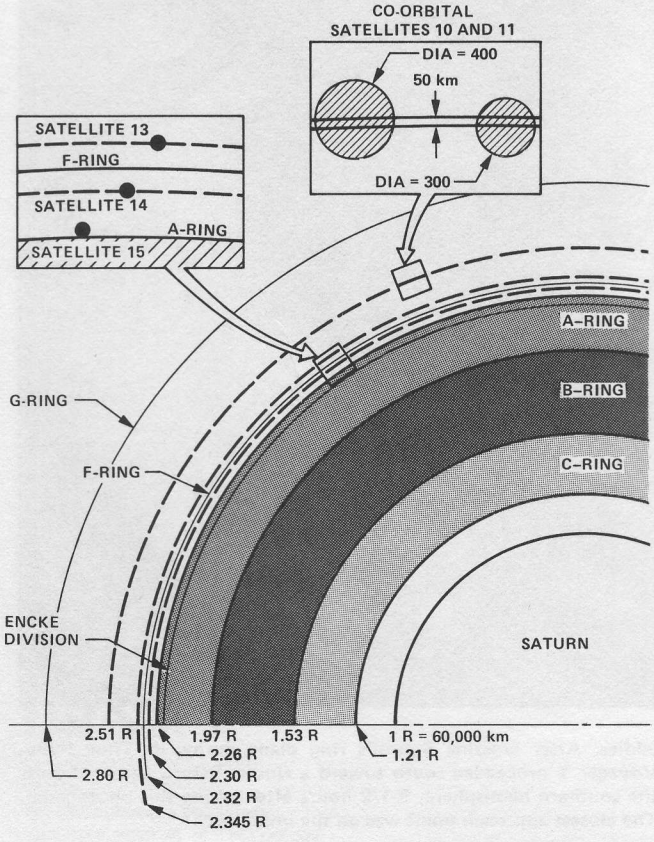
Voyager 1 11/12/80 750,000 km (470,000 mi) P-23099

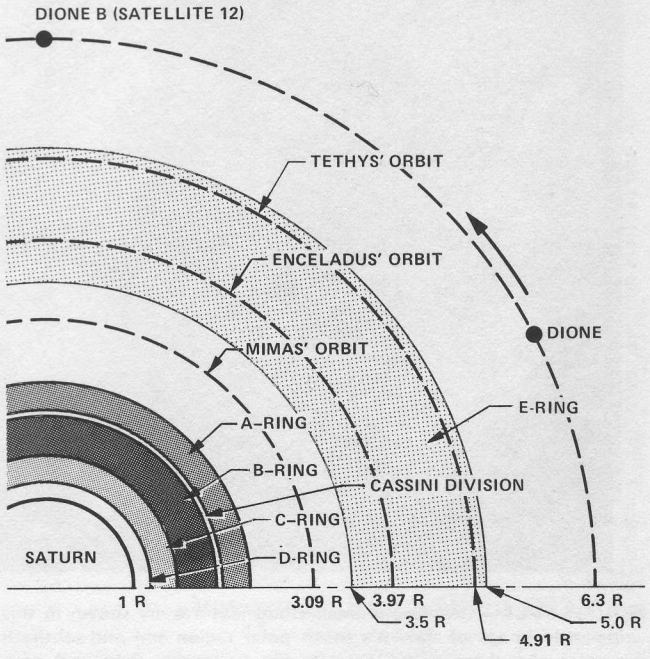
BRAIDED F-RING – Two narrow, braided, bright rings that trace distinct orbits, as well as a broader, very diffuse component about 35 kilometers (20 miles) in width can be seen in the F-ring. Also seen are "knots," which probably are local clumps of ring material, but may be mini-moons. The photo was taken from the unilluminated face of the rings.

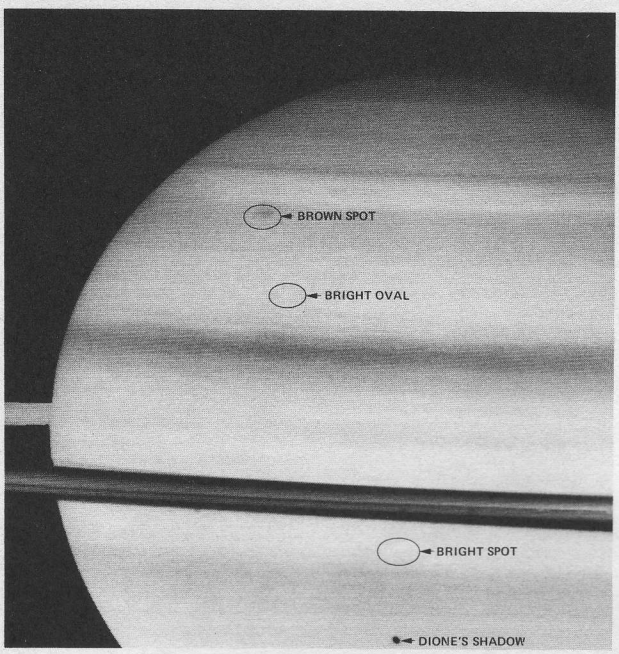


Voyager 1 11/12/80 128,000 km (79,500 mi)

RHEA – One of the highest-resolution color images of Rhea shows one of the satellite's most heavily cratered areas, indicating an ancient surface dating back to the period immediately following the formation of the planets 4.5 billion years ago. The photograph shows surface features about 2.5 kilometers (1.5 miles) in diameter, similar to a view of Earth's Moon through a telescope. Other areas of Rhea's surface are deficient in the very large (100 kilometers or 62 miles or larger) craters, indicating a change in the nature of the impacting bodies and an early period of surface activity. White areas on the edges of several of the craters are probably fresh ice exposed on steep slopes or possibly deposited by volatiles leaking from fractured regions.

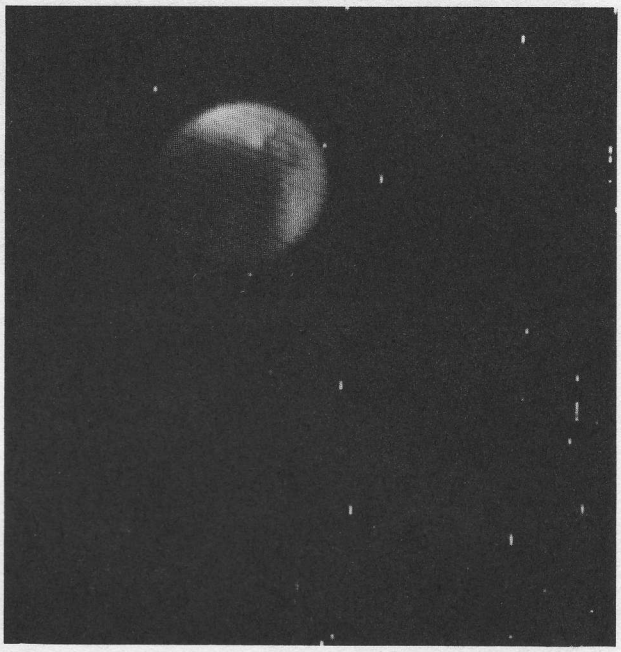






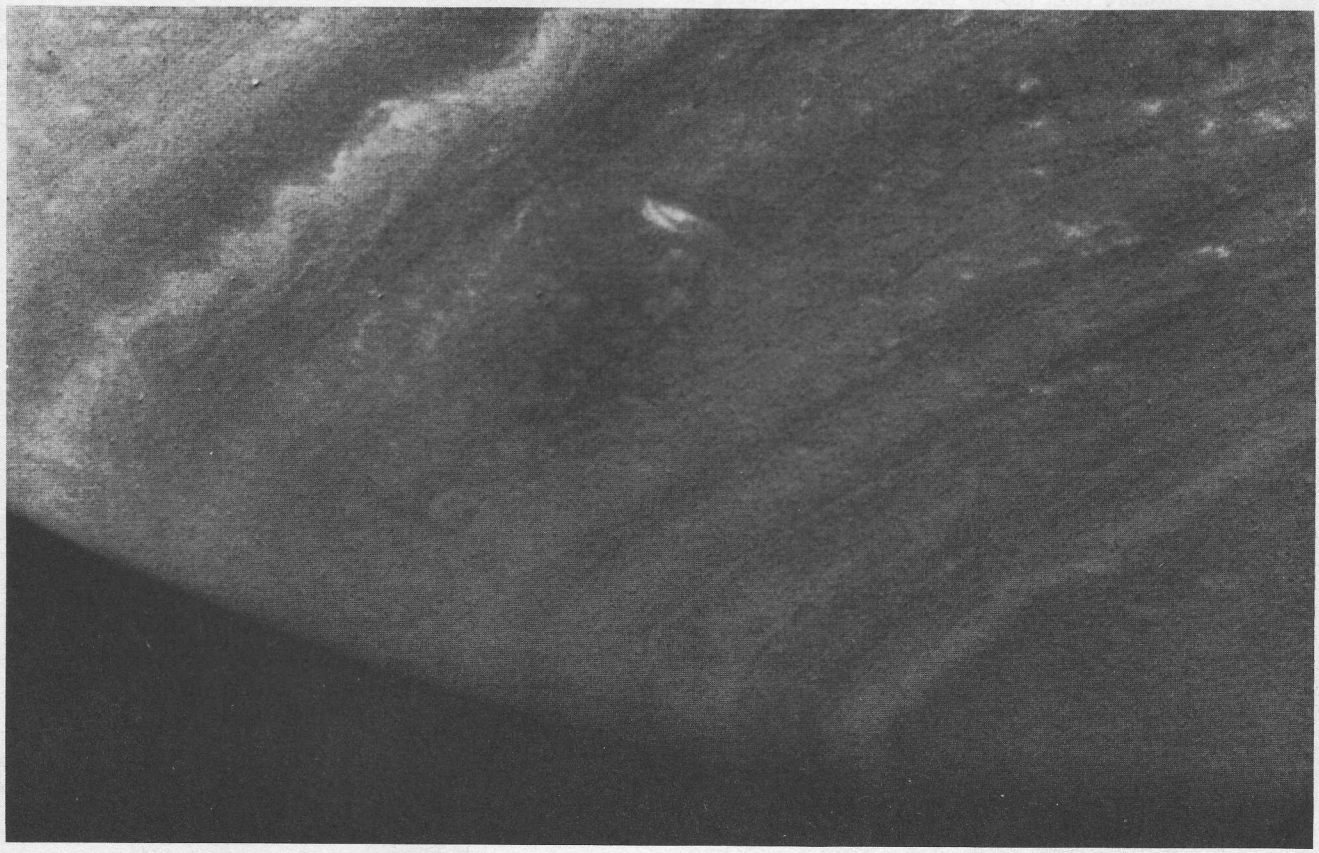
Voyager 1 11/11/80 1,750,000 km (1,087,000 mi)

MUTED FEATURES – Low-level contrast between features in Saturn's cloud deck is shown in this composite photograph. The brown spot in the northern hemisphere (center, left) and the bright oval below it have been observed by Voyager for several weeks. Wind speeds in this latitudinal area are as high as 60 meters per second (90 miles per hour), so distances between these features increase rapidly. A deep atmospheric haze mutes all features. The banded belt/zone structure extends to higher latitudes than at Jupiter. Taken near ring plane crossing, the edge-on view of the rings seems to blend into the ring shadows cast on the planet's face.



Voyager 1 11/12/80 3,200,000 km (1,900,000 mi)

IAPETUS – A large circular feature about 200 kilometers (120 miles) across with a dark spot in its center is visible in this photograph of Saturn's satellite Iapetus. The satellite's leading hemisphere is to the left, and the trailing hemisphere, which is about four to five times brighter, is to the right. The large circular feature is most probably a large impact structure outlined by dark material, possibly thrown out by the impact.

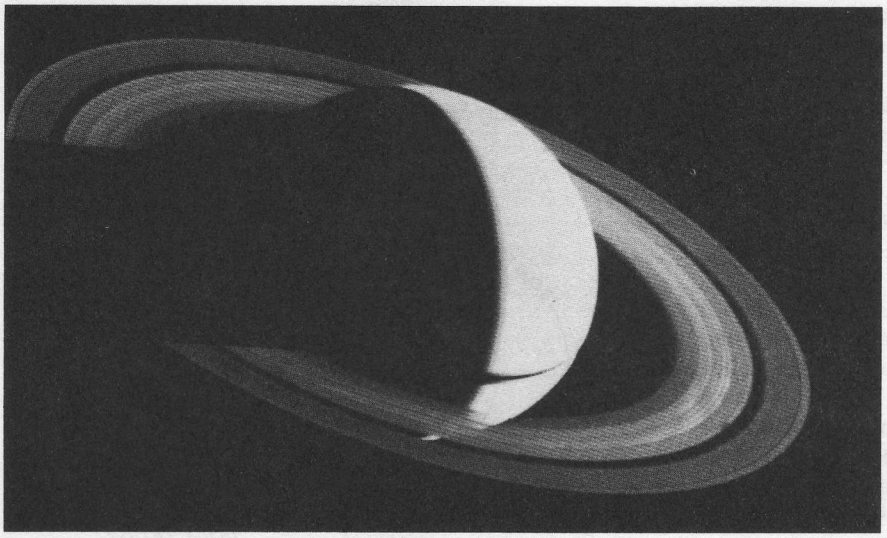


Voyager 1 11/12/80 442,000 km (265,000 mi)

SOUTH POLE – Numerous small cloud features are shown in this wide-angle image of Saturn's south polar region and mid-southern latitudes. At these polar latitudes the large-scale light and dark bands break down into small-scale features, seen here as waves and eddies. After crossing Saturn's ring plane during its Titan flyby, Voyager 1 proceeded south toward a closest Saturn approach over the southern hemisphere, 5-1/2 hours after taking this photograph. The closest approach point was on the unlit side.

Voyager Bulletin

MISSION STATUS REPORT NO. 60 DECEMBER 5, 1980



Voyager 1 11/16/80 5,300,000 km (3,300,000 mi.)

POST-ENCOUNTER – Looking back, Voyager 1 observed Saturn and its rings from this unique perspective four days after flying past the planet. A few of the spoke-like ring features discovered by Voyager appear in the rings as bright patches in this image. At left, Saturn's shadow falls upon the rings, and the bright Saturn crescent is seen through all but the densest portion of the rings. The ring shadows are seen near the planet's equator. From Saturn, Voyager 1 is on a trajectory taking the spacecraft out of the ecliptic plane, away from the Sun and eventually out of the solar system (by about 1990). Voyager 1's flight path through intergalactic space is in the direction of the constellation Ophiuchus.

Update

Voyager 1 is continuing its post-encounter observations of the Saturn system. The spacecraft is now about 29 million kilometers (18 million miles) beyond the planet, travelling with a heliocentric velocity of about 21.6 kilometers per second (more than 48,000 miles per hour). Radio signals from the ship reach earth 83 minutes after transmission, travelling about 1.5 billion kilometers (930 million miles) to get here.

Voyager 2, eight and one-half months from its closest approach to Saturn in August 1981, is in good health and operating well. It is about 248 million kilometers (154 million miles) from the planet, travelling with a heliocentric velocity of about 16.6 kilometers per second (37,000 miles per hour). Radio signals between earth and Voyager 2 travel about 69 minutes each way. Voyager 2's distance to earth is over 1.2 billion kilometers (770 million miles).

Post-Encounter Activities

Voyager 1's post-Saturn encounter observations will continue through December 15, 1980. Aside from calibrations, no further imaging observations are planned after December 19, but the fields and particles sensing instruments will continue to be operated and to sample the interplanetary medium.

Wide-angle imaging frames taken on November 16 - 18 as Voyager 1 soared up and away from Saturn have been assembled into a post-encounter time-lapse movie of the planet and rings rotation. Voyager 1 put about 2.0 million miles between itself and the planet while taking these pictures. The B-ring spokes, which appeared as dark streaks in inbound photographs, appear bright in outbound photographs, indicating that they scatter light strongly in a forward direction. Infrared observations occurred simultaneously with these imaging sequences.

Through mid-December, the spacecraft will continue a daily cycle of Saturn imaging, ultraviolet observations of the Saturn system, infrared composition measurements of the planet, celestial mechanics measurements, and plasma wave/planetary radio astronomy data.

SATURN RESULTS

Magnetosphere

Of the six planets in the solar system which have been studied so far at close range, five – Mercury, Earth, Mars, Jupiter, and Saturn – have intrinsic magnetic fields. These fields are generated by currents which flow in the interiors of the planets, and are mainly dipolar; i.e., current along the magnetic field lines flows from pole to pole.

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The magnetic field influences not only the planet, but a considerable area of space around the planet, as well. This area is called the magnetosphere. Saturn's magnetosphere extends outward from the planet nearly one million miles – making it about five times larger than Earth's magnetosphere but only one-third as large as Jupiter's. The rings, Mimas, Enceladus, Tethys, Dione, and Rhea are totally within the magnetosphere at all times, as are the small, newly-discovered satellites.

Although Saturn's largest satellite, Titan, is usually inside the magnetosphere, it is sometimes outside in the solar wind, due to fluctuations of the magnetospheric boundary. The size of the magnetosphere is influenced by increases or decreases in the intensity of the flow of charged particles streaming from the sun (the solar wind). Solar flares, for example, increase the solar wind intensity, but the effect may take several weeks to reach the outer planets.

At the time of Voyager 1's passage, Titan was inside Saturn's magnetosphere. The data are being studied to determine how the magnetosphere interacts with Titan and its thick nitrogen-rich atmosphere.

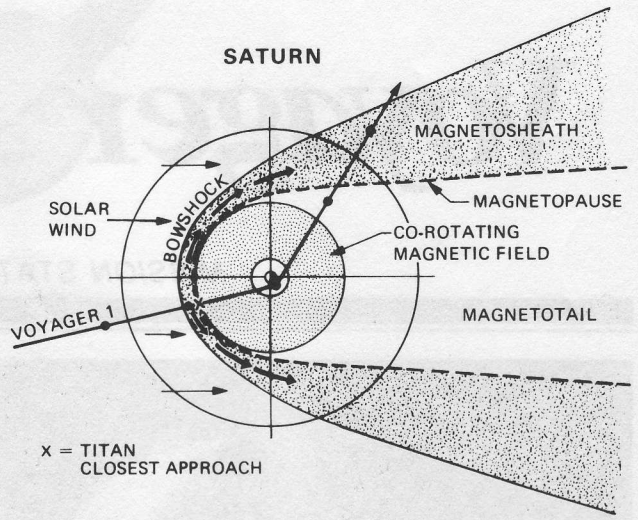
As is the case at Jupiter, charged particles in Saturn's magnetosphere are dragged along by the magnetic field and rotate with the planet at the planet's rotation rate – about 10 hours 40 minutes. At Titan, about 1.2 million kilometers from the planet's center, these particles speed past at almost 200 kilometers per second (447,000 miles per hour)! For comparison, particles in Jupiter's magnetic field are travelling about 77 kilometers per second (172,000 miles per hour) at Io's orbital distance.

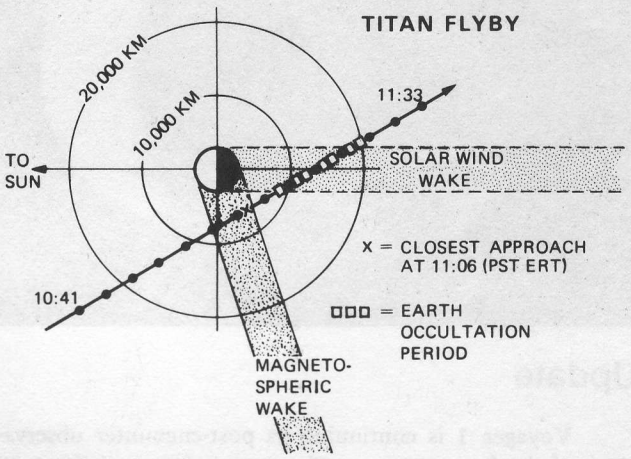
The flow of the co-rotating magnetosphere around Titan leaves a "wake" much like that left by a motorboat. Inside this wake region, the ions and electrons are colder, slower, and of higher density than the surrounding magnetospheric particles. Currents in this wake form a magnetic tail which extends in front of Titan as its orbits. The magnetosphere rotates faster than Titan does.

The source of particles in Saturn's magnetosphere is still under investigation. The low-energy charged particles (LECP) instrument's detection of fast-moving (7000 miles per second) molecular hydrogen in Saturn's magnetosphere suggests that Titan's atmosphere may be an important source. The LECP also found that the energies of fast ions in Saturn's magnetosphere are typically ten times less than those in Jupiter's.

Voyager 1 met Saturn's bowshock wave on November 11, about 1.572 million kilometers from the planet's center. The bowshock is the outer boundary of a planet's magnetic influence where particles streaming from the sun at supersonic speeds drop to subsonic speeds as they meet particles more influenced by a planet's magnetic field. The actual boundary of the co-rotating magnetosphere is called the magnetopause, and the area between the bowshock and magnetopause is the magnetosheath. After crossing the bowshock, Voyager 1 travelled through the magnetosheath and crossed the magnetopause five times in about an hour as this boundary also ebbed and flowed. The first magnetopause crossing was a little more than two hours after the bowshock crossing. The final inbound crossing of the magnetopause was about 1.374 million kilometers from Saturn's center.

As the solar wind streams around the planet and its magnetosphere, the magnetosphere stretches out into a tail – a magnetotail – behind the planet streaming *away* from the sun. Because of its curved flight path, Voyager 1





spent only a few days in Saturn's magnetotail, compared to several weeks in Jupiter's. The first outbound magnetopause crossing occurred November 14 about 2.580 million kilometers past the planet. By November 16 at 4.680 million kilometers, Voyager 1 passed out of Saturn's magnetic domain and back into the solar wind for good.

Satellites such as Titan and Jupiter's Io have been called naturally-occurring power stations. As Titan moves through Saturn's co-rotating magnetic field, its ionosphere acts as an armature to produce voltage and power. Voyager 1 measured these to be about 6000 volts and 20 megawatts, respectively. The magnetic field at the inner regions of Titan's wake is weaker than outside the wake. Titan probably has no intrinsic magnetic field, indicating that it does not possess a liquid, conducting core. If Titan does possess a magnetic field, it can be no stronger than one-tenth of one percent of Earth's magnetic field, or about 30 nano-Teslas, as measured by Voyager's magnetometers.

Surrounding Titan and its orbit and extending nearly a million kilometers inward toward the planet to the orbit of Rhea, the ultraviolet spectrometer detected an enormous, flattened cloud of uncharged hydrogen atoms forming a doughnut-like torus around the planet. These atoms do not rotate with the magnetosphere. The mass of the torus is estimated to be 25,000 tons and the density about 10 atoms per cubic centimeter.

At the planet, the rings appear to be an effective shield or absorber of charged particles, but in the process are affected themselves. The magnetic effects on the rings are evidenced by the B-ring spokes and lightning-like electrical discharges in the rings.

Voyager Bulletin

MISSION STATUS REPORT NO. 61 JANUARY 14, 1981

The dust has settled. All the visiting scientists have gathered their reams of computer printouts and reels of magnetic tapes and gone home to sift through them. The hordes of press people and guests have left. Initial findings have been reported. Planning for Voyager 2's Saturn event next August is moving forward, with many changes in the nuts and bolts details caused by Voyager 1's insights into this fascinating realm.

What have we learned? That there is still much more to learn. That Saturn is not just a colder version of Jupiter, nor are its satellites just miniature Galileans. Its magnetic field is pretty weird. And its rings . . . well, that's a pretty long story by itself.

Voyager 1 has completed its planetary exploration. No other planets lie in its path, nor can its course be redirected now to any other planet. It is exiting the solar system, climbing up out of the ecliptic bound towards the constellation Ophiuchus, which it may chase for aeons and never catch.

But this remarkable spacecraft is not being shut down or turned off. There are those who are interested in what lies beyond the planets, and between them. Voyager 1 will continue to test the interplanetary waters, telling us about the solar wind that blows over and around all the planets – our inhabited earth as well as the cold, silent worlds that share our sun. Some day, Voyager 1 and other interplanetary spacecraft will reach the heliopause – the outer edge of the sun's magnetic influence. In other words, the edge of the solar system. We don't know where this is, or when we will reach it. Like a planet's magnetosphere, the heliosphere probably increases and decreases in size according to the sun's activity. That's why the Deep Space Network is tracking these spacecraft, each headed in slightly different directions, to get even a rough idea of how big this invisible portion of our solar system really is. The best guess right now is that Voyager 1 will cross the heliopause around 1990, at forty times earth's distance from the sun. Right now it is slightly more than ten times earth's distance from the sun.

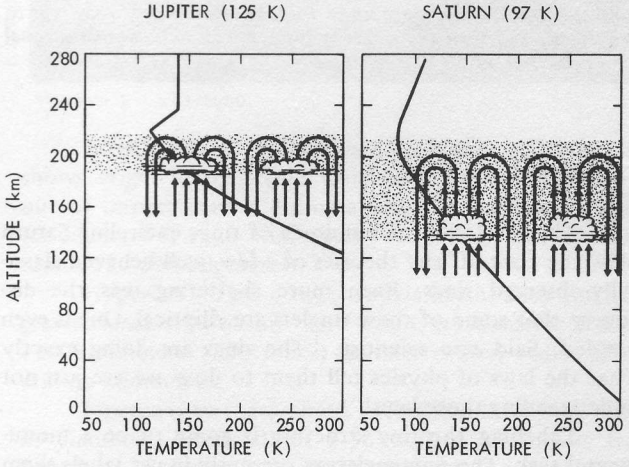
This is the last scheduled Voyager bulletin before Voyager 2 begins its Saturn observations in June. A short summary of Voyager 1's findings on Saturn, the rings, and the satellites is given below.

Saturn Science Results

The Planet

The body of Saturn has a strange, delicate beauty all its own. After seeing the wild, colorful turbulence of Jupiter, many looked forward to seeing more of the same on Saturn. But Saturn's markings are muted by a thick haze layer above the cloud tops, perhaps three times thicker than a similar haze on Jupiter. And Saturn is colder – perhaps 25 to 30 K colder at the cloudtops than Jupiter. One might expect it to be even colder since it is nearly twice as far from the sun as Jupiter. But Saturn probably has some sort of heat-producing mechanism deep in its interior. Saturn also rotates very fast (once each 10 hours 40 minutes) for its size (75,000 miles in diameter). Near Saturn's equator, the wind speeds are four times as great as on Jupiter, and cloud features tend to be short-lived in this gusty environment. These equatorial winds blow more than 1600 kilometers (1000 miles) per hour.

Below this blanket of haze, Saturn's atmosphere, like Jupiter's, forms relatively long-lived alternating dark belts and light zones, circulating storm regions, and other unique dark and light cloud markings. The light and dark bands on both planets are not static, but vary over periods of one to



At Saturn, clouds form lower in the atmosphere than at Jupiter. Saturn also has a thicker haze layer. Upwelling currents diverge at higher altitudes above the cloud decks. Also, the atmospheric temperatures rise more sharply at Jupiter, as shown in the curves.

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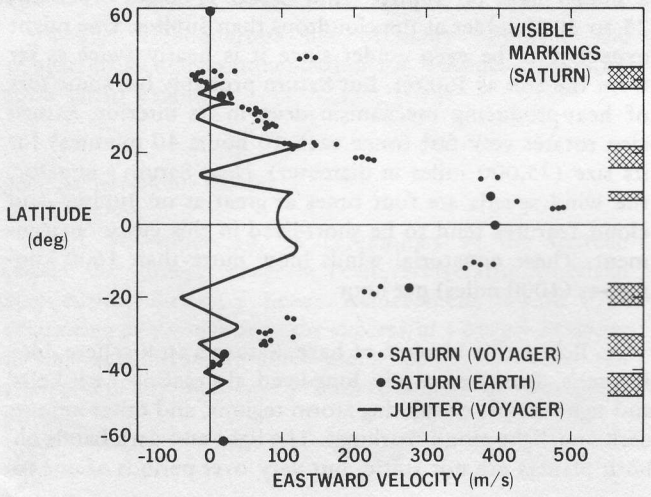
ten years. Saturn's bands seem to be about twice as wide as Jupiter's, and extend into the polar regions. While Jovian winds appear to be closely linked to the belt-zone structure, this does not appear to be true at Saturn. Oval spots have been identified in Saturn's atmosphere and will be tracked by Voyager 2 to learn more about the planet's atmospheric circulation patterns.

Auroras seen near Saturn's poles are comparable in intensity to earth's polar auroras (the "northern and southern lights"). Saturn's auroras are probably caused by molecular hydrogen high in the atmosphere. The ultraviolet spectrometer also detected auroral-type emissions near the illuminated limbs of the planet, and Voyager 2 will continue to study these phenomena.

Radio signals typical of lightning discharges have been detected, but lightning has not been photographed on Saturn since the rings reflect so much light onto the dark side of the planet that it is too bright to see the lightning. The lightning-like discharges are believed to originate in the rings rather than in the atmosphere.



Wind speeds at Saturn range up to 1600 kilometers per hour, four to five times faster than any winds at Jupiter. This plot compares zonal wind velocities on the two planets.

The Rings

The revelation of hundreds of rings encircling Saturn blew the cork off any theories of a few, well-behaved classically-observed rings. Even more shattering was the discovery that some of these ringlets are elliptical. One is even braided. Said one scientist, "The rings are doing exactly what the laws of physics tell them to do – we are just not understanding those laws!"

Labelling the ring structure is going to be a monumental task. The nomenclature presently in use labels them as (moving outward from the planet) D, C, B, A, F, and E, named in order of their discovery. Besides the obvious gaggle of rings in the A, B, and C rings, Voyager 1 confirmed the existence of the D-ring closest to the cloudtops, and found two more rings which lie between the F and E rings. The F-ring was also found to be comprised of three interwoven ringlets. Not even the empty spaces are really empty, it seems. At least twenty ringlets fill this 3500-kilometer wide space between the A and B-rings. The A-ring's Encke Division may truly be empty, however.

Analysis of the spacecraft's radio signals as they passed through ring material on the way to earth (a ring occultation experiment) shows that the particles, mostly ice or frosted rock, may range in size anywhere from dust to boulders. The C-ring has chunks that average about two meters across, while the E-ring has mostly very fine particles. There certainly is a lot of bumping and grinding going on between ring particles as they orbit. The optical densities of the rings, as indicated by the amount of light they allow to pass through, also vary, with the optical thickness of the B-ring being the greatest.

Voyager 1 also provided clues to the puzzle of the rings' stability – why have they existed for so long? Why do the particles continue to orbit the planet rather than drifting off into space? A theory that large chunks, or small satellites, rotating within the rings may control their orbits gained stature when several small satellites were discovered near the outer edge of the A-ring and on either side of the F-ring. Satellites 13 and 14 flank the F-ring, herding it much like sheepdogs moving an unruly flock down a country lane. Satellite 15 is thought to control the outer edge of the A-ring.

The rings probably do not possess a dense atmosphere, but they almost certainly have electric fields, dielectric particles, and collisions between particles – all part of the essential conditions for earth-like lightning.

Saturn's magnetic field appears to interact with the B-ring particles to cause the spoke-like phenomena seen in many pictures. Electrostatic charging may temporarily levitate very fine particles above the ring surface. These fine particles scatter light differently than the larger particles in the denser body of the ring, and thus appear dark from some viewing angles and bright from others.

The Satellites

As Titan loomed larger and larger on November 10 and 11, it still looked like a fuzzy yellow tennis ball, and spectators thought at last they were going to find some boring satellites. Not so. Saturn's satellites present a new class of icy, intermediate-sized objects unlike any planetary moons thus far explored, and unlike the asteroids as well. These satellites are generally divided into three discussion areas: the new small moons, giant Titan, and the intermediate-sized objects.

To date, Voyager 1 has confirmed six new satellites at Saturn. This includes confirmation of one satellite spotted three times by Pioneer 11 in September 1979. All of these satellites were photographed, but only two, satellites 10 and 11, from close enough to determine their shapes. Both of these are irregularly-shaped with their long axes pointed toward Saturn, and are apparently composed of water ice. They share an orbit about 91,000 kilometers (57,000 miles) above Saturn's cloud tops and thus are referred to as the "co-orbitals".

Little is known about satellites 12 through 15 other than their orbits. Satellite 12 occupies the orbit of Dione, slowly oscillating about a point 60° ahead of Dione. Satellites 13, 14, and 15 orbit just outside the F-ring, just inside the F-ring, and just outside the A-ring, respectively.

Rivers of methane may cut through glaciers of methane under a nitrogen sky on Titan. Voyager data confirm that the main constituent of Titan's atmosphere is nitrogen rather than methane as previously thought, and this means that Titan is the only other place besides earth known to have a nitrogen-based atmosphere.

Near the surface, Titan's atmospheric temperature and pressure are near the triple point of methane, which means that it can probably exist as a solid, liquid, and a gas. (The triple point for water, for example, is 32°F and 6 millibars pressure, at which point it can be liquid water, ice, or water vapor.) Methane probably plays the same role on Titan that water plays on earth as rain, snow, ice, and gas. The clouds may drop liquid methane rain on the surface.

Voyager 1 measured Titan's surface temperature at about 92 Kelvin (about −293°F). The minimum atmospheric temperature of about 70 Kelvin (−333°F) is reached at the 100 millibar pressure level, about 50 to 70 kilometers above Titan's surface. The atmospheric pressure at the surface is fifty percent greater than at earth, and the atmosphere is five times as deep as earth's.

The spacecraft's radio signals reached the surface of Titan – something the cameras could not do because of the thick atmosphere. Titan appears to have a dark north polar hood and a three-tiered haze layer above the atmosphere.

Once thought to be the largest satellite in the solar system, Titan has been dethroned. Its diameter has been measured to be about 5120 kilometers (3200 miles). The new king is Jupiter's Ganymede, 5276 kilometers (3278 miles) in diameter. Both satellites are larger than the planet Mercury.

One of the mysteries remaining is why Titan is the only satellite with a substantial atmosphere, while Ganymede, slightly larger, has at best a very tenuous atmosphere.

Titan exerts considerable gravitational forces on other bodies, and may be a factor in tidal heating of Enceladus. Titan's interaction with Saturn's magnetosphere is of keen interest, for as the magnetosphere ebbs and flows with the varying pressure of the solar wind, the magnetopause (the outer edge) sometimes sweeps across Titan, leaving Titan temporarily completely outside the magnetic influence of Saturn. When Titan is within the magnetopause, the magnetosphere also leaves a wake as it flows past the satellite.

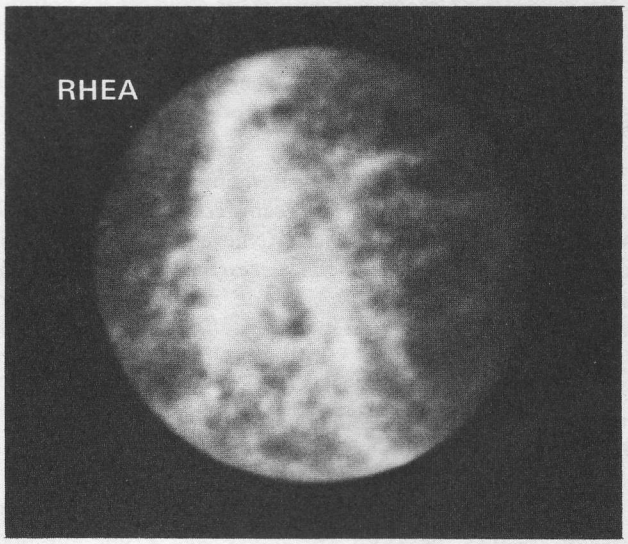
The inner moons – Mimas, Enceladus, Tethys, Dione, and Rhea – seem to be composed mainly of water ice. Work is continuing to unravel the chemical composition of these bodies, which may also contain ammonia compounds. The thermal histories of small satellites – their heating or cooling – depends on their composition because of the different melting temperatures of various ices.

About 188,220 kilometers from Saturn*, Mimas (mī-mus) is about 390 kilometers (240 miles) in diameter – about half the size of the largest asteroids. At some point in its history, Mimas was rocked by an impact which left a gaping center nearly one-fourth the diameter of the satellite itself. Such a blow must have nearly shattered the satellite. The crater walls are about 9 kilometers (5.6 miles) high, with a central peak 4 to 5 kilometers (2.5-3 miles) tall. Voyager 1 photographed parts of Mimas with a resolution of 2 kilometers.

Of the five inner moons, only Enceladus (en sel a dus) shows no evidence of any impact craters (at a scale of 12 kilometers or 7 miles). Voyager 2 will get a much closer look at Enceladus in August. Since Enceladus is locked in a 2:1 orbital resonance with Dione (one orbit for every two by Dione), there is speculation that this causes the same type of tidal stresses suffered by Io in the tug-of-war between Jupiter and Europa. There is also speculation that Enceladus may be a source of E-ring particles since the maximum intensity of the E-ring occurs near the orbit of Enceladus, about 240,190 kilometers from Saturn. Its diameter is about 490 kilometers (300 miles).

A wide (60-kilometer or 40-mile) valley stretches 750 kilometers (470 miles) across the surface of Tethys (tē this). The trench may be a crustal fracture caused by a blow which formed an 180-kilometer (110-mile) impact crater on the other side of the satellite. Tethys may be pure ice. Slightly larger than the largest asteroids, it has a diameter of about 1050 kilometers (650 miles) and orbits about 296,560 kilometers from Saturn's center.

Several sinuous valleys, some of which appear to branch, are visible on Dione's surface. Bright wispy streaks stand out against an already highly-reflective surface, and are probably the result of relatively fresh ice ejecta thrown out of more recent (geologically-speaking) impact craters. Dione (dī ō nē) is slightly more dense than the other five inner moons, breaking a pattern of progressively less dense satellites moving out from the planet. Dione may be 30 to 70 percent rock. Its diameter is about 1110 kilometers (690 miles) and its orbital distance is 379,070 kilometers.



Voyager 1 11/6/80

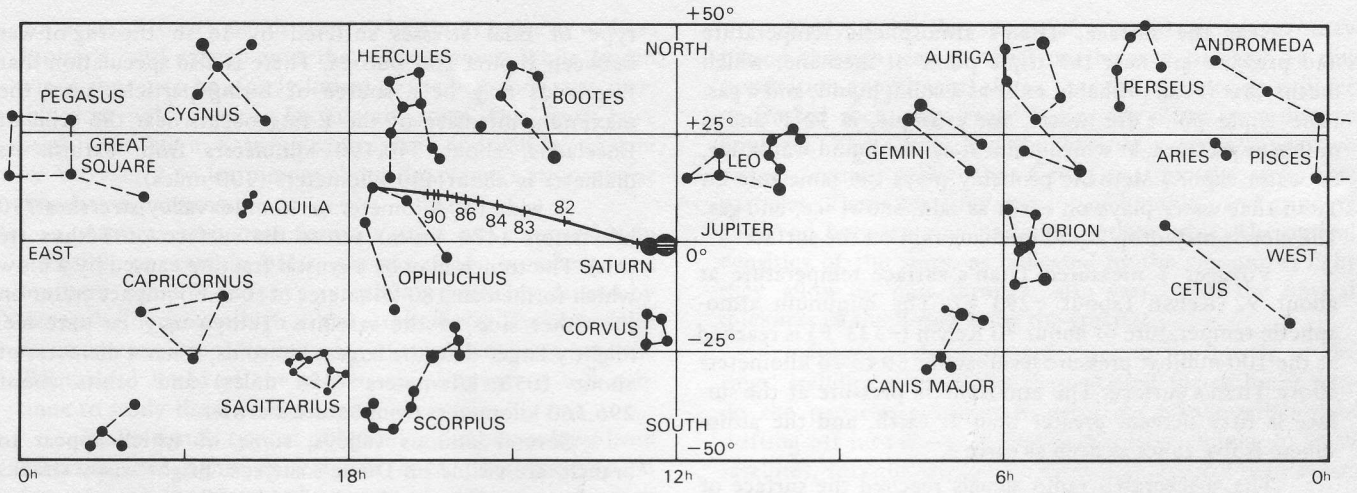
Rhea's (rē a) surface is also highly reflective and shows bright wispy breaks which may be fresh ice thrown out of impact craters during a later bombardment period. Its diameter is 1520 kilometers (940 miles), and its orbital radius 527,830 kilometers.

Hyperion (hī pēr ē an) is apparently non-icy and has a gravitational relationship with Titan. Its diameter is about 310 kilometers (190 miles) and its orbital radius is 1.5 million kilometers.

Iapetus (ī ap i tas), about 1450 kilometers (900 miles) in diameter, orbits about 3.56 million kilometers from Saturn and has light and dark hemispheres. The leading face (that which faces forward as Iapetus orbits Saturn) reflects only about one-fifth as much light as the bright trailing side. Its orbit is inclined significantly to the plane in which the rings and other inner satellites orbit.

Tiny Phoebe (fē bē), in a retrograde (clockwise as seen from above) orbit highly inclined to the ring plane, will have to wait to be photographed until Voyager 2 arrives at Saturn next summer. Daily observations will begin in June, with closest approach to Saturn on August 25, 1981 at 8:24 pm PDT (spacecraft event time).

*Unless otherwise stated, the orbital distances are from the center of Saturn.



Voyager 1, having completed its tours of the Jupiter and Saturn systems, is heading out of the solar system toward the constellation Ophiuchus. As the years pass, a stargazer might imagine seeing it at the above points. Ophiuchus is moving away faster than Voyager 1 is approaching.

Update

NASA Headquarters has officially approved the Voyager Project's recommendation for Voyager 2's continuation on to Uranus.

Space Achievement Award

On November 10, in ceremonies at the Caltech campus, the Voyager Program Team received the American Astronautical Society's Space Achievement Award *"for outstanding performance in the successful Voyager Program and in recognition of their major contribution to the advancement of mankind's understanding of the Solar System."*

Plasma Instrument Ill

Voyager 1's plasma instrument stopped transmitting useable science data on November 23, 1980, and has returned no useful science data since then. The instrument remains on, however, while engineers and scientists continue to look for ways to correct the problem or work around it.

Soon after the problem was detected, several calibrations were made. Data from these tests appeared normal except for the high-voltage calibrations of the modulator, that part of the instrument that electrically switches between active and reference sensors. There may be some similarity between this problem and one that existed between February and May 1978, which was corrected.

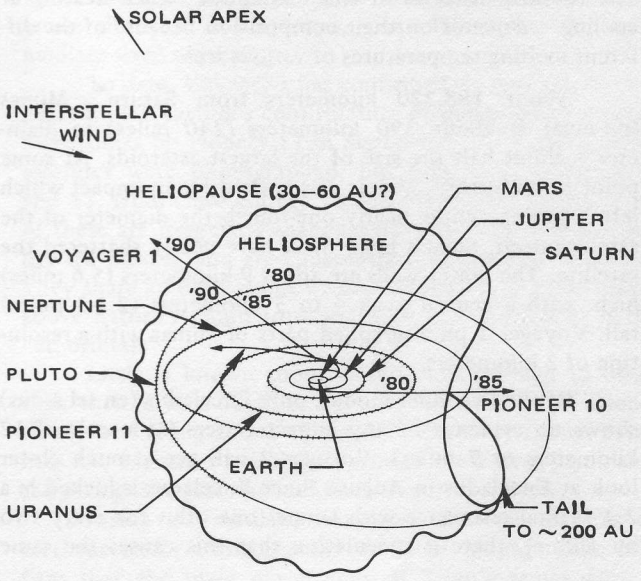
The problem occurred after the instrument had completed all of its measurements of the Saturn system, and after a spacecraft maneuver in which the sun illuminated portions of the instrument for about 19 hours.

The plasma experiment measures the velocity, density, and temperature of interplanetary plasma for a wide range of flow directions in both the solar wind and magnetospheres. Plasma refers to the clouds of low density, high-speed, ionized gases which originate from the sun and other stars. The plasma experiment is one of several aboard the spacecraft which will continue to sample the solar wind as Voyager 1 heads out of the solar system.

Saturn Satellites Characteristics Summary

	Radius (km)	Density	Albedo
Leading Co-Orbital	~80	?	~0.4
Trailing Co-Orbital	~40-45*	?	~0.4
Mimas	195 ± 5	1.21 ± 0.10	0.6 ± 0.1
Enceladus	245 ± 15	1.12 ± 0.52	1.0 ± 0.1
Tethys	525 ± 10	1.03 ± 0.06	0.8 ± 0.1
Dione	555 ± 10	1.43 ± 0.09	0.6 ± 0.1
Rhea	760 ± 10	1.33 ± 0.10	0.7 ± 0.1
Titan	2560 ± 30	1.94 ± 0.02	–
Hyperion	155 ± 20	?	0.3 ± 0.1
Iapetus	725 ± 20	1.24 ± 0.48	±0.5 ±0.1 (bright side)

*Not circular



Although their planetary explorations are over, spacecraft such as Pioneers 10 and 11 and the Voyagers will be tracked for many years as they head for the outer reaches of the solar system.

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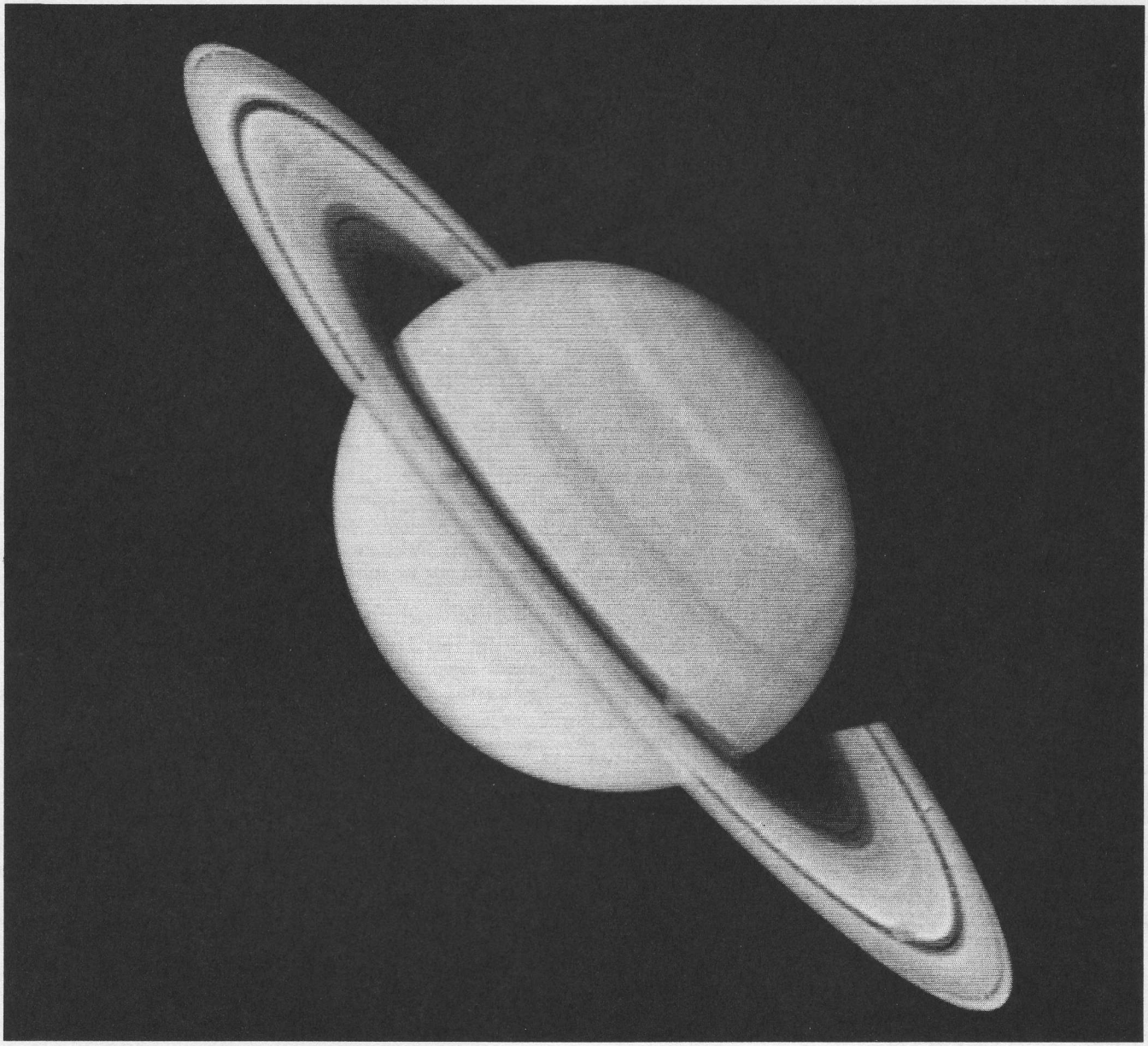

Voyager 2 captured this image of Saturn on June 14, 1981, from a distance of 69 million kilometers (41 million miles). Banding can clearly be seen in the northern hemisphere. Starting at the ring tips, the following features can be seen: outer A-Ring; dark, narrow Encke Division; inner A-Ring; wider, dark Cassini Division; wide B-Ring; and the C-Ring. The shadow of the planet cuts off the rings' image behind the planet, while the rings' shadows fall across the equatorial zone, and blend with the C-Ring in this view.

NASA

National Aeronautics and
Space Administration

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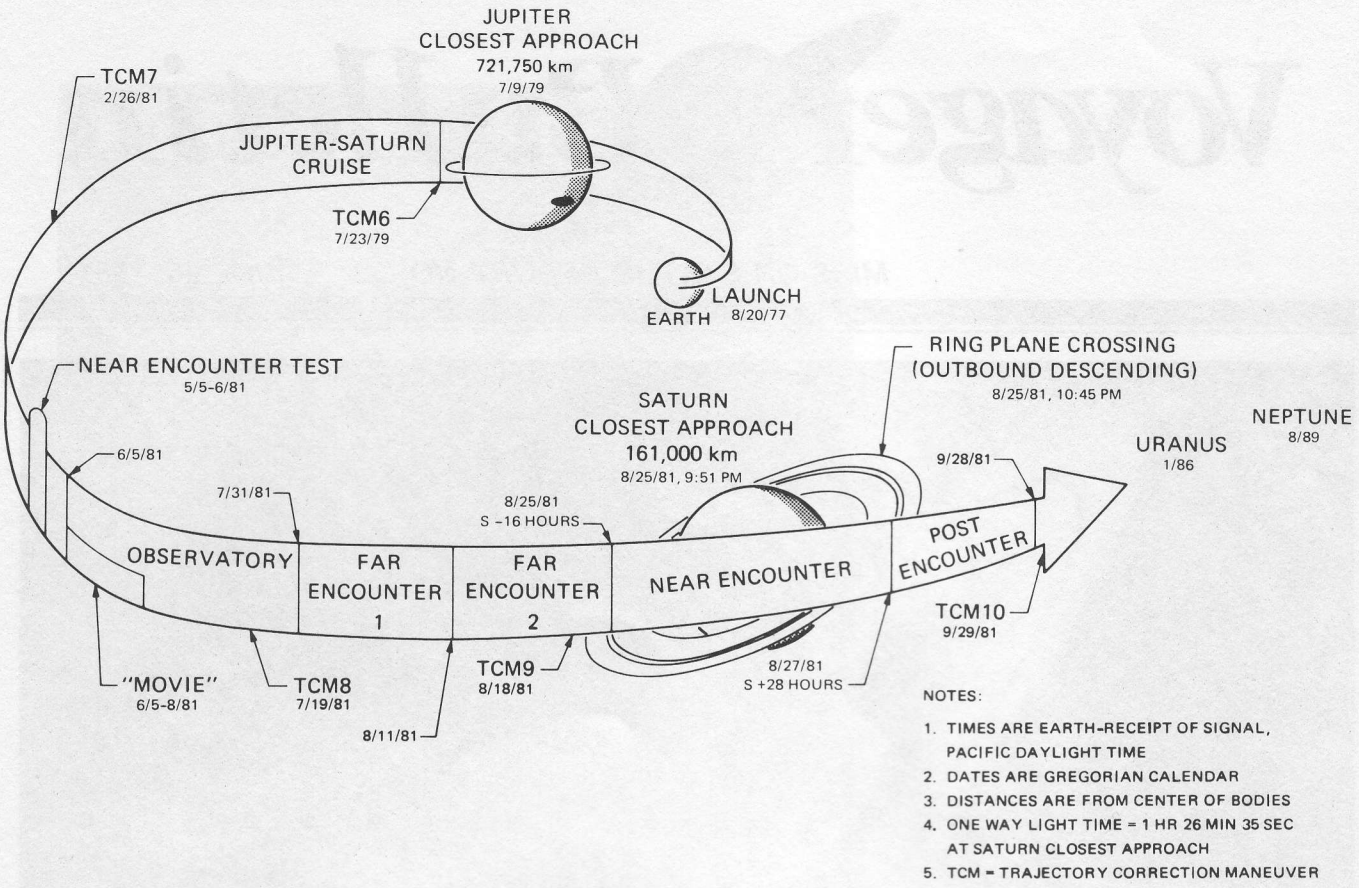
Recorded Mission Status (213) 354-7237
Status Bulletin Editor (213) 354-4438
Public Information Office (213) 354-5011



Voyager 2's Saturn Observations

The Saturn encounter activities have been divided into five phases, chosen based on the field-of-view of the narrow-angle camera in relation to the distance to the planet. The five phases are Observatory, Far Encounter 1, Far Encounter 2, Near Encounter and Post Encounter.

Observatory began on June 5, about 82 days before closest approach, and will run eight weeks. During this period, a short-term history of the Saturn system will be compiled. The phase began with 43 hours of nearly-continuous photography of four Saturn rotations. The images are being assembled into a "rotation movie", to be used to study changes in the atmosphere and rings over a period of time.

Throughout this phase, the narrow-angle camera will take pictures of Saturn every 72° longitude of the planet's rotation. These pictures may be assembled into an inbound "zoom" movie. The ultraviolet spectrometer will scan across the Saturn system, out to 25 Saturn radii on either side of the planet. The instrument will map the intensity of emissions from Titan's orbit, and try to identify chemical species and densities.

Radio emissions from the planet will be sampled daily by the planetary radio astronomy experiment, while the plasma wave instrument will search for plasma variations several times during the phase. Using the spacecraft's radio, experimenters will take measurements for studies of celestial mechanics and gravitational redshift.

A trajectory correction maneuver to adjust the flight path will be performed on July 19. Numerous other calibrations will also be done during the Observatory phase.

By July 31, 26 days before closest approach, the narrow-angle camera's field-of-view will no longer reliably capture the entire planet in one frame. Two-by-two mosaics (four pictures will be needed to photograph the entire planet) will signal the start of the next phase, **Far Encounter 1**. Voyager 2 will then be 24.7 million kilometers (15.3 million miles) from Saturn. The repetitive observations of the Observatory phase will continue with modifications in pointing angles and frequency. The satellite Iapetus will be studied by both the cameras and the photopolarimeter. The ultraviolet spectrometer will scan the Saturn system vertically as well as horizontally from one side of Titan's orbit to the other.

Twelve days later, the **Far Encounter 2** phase will begin when two-by-two mosaics no longer suffice to cover the entire planet. Voyager 2 will be 14.4 million kilometers (8.9 million miles) from Saturn when Far Encounter 2 begins on August 11. A trajectory correction maneuver is scheduled for August 18. All instruments will be gathering data on the planet, most of the satellites, and the near-Saturn plasma. The narrow-angle camera will focus on the B-Ring for three rotations about 12 days before closest approach to the planet, to produce a movie of the dynamics in the B-Ring and its peculiar "spokes". Closest approaches to Iapetus, Hyperion, and Titan, as well as the magnetopause crossing, occur late in the Far Encounter 2 phase – as late as 18 hours before closest approach to Saturn.

The 43-1/2-hour **Near Encounter** phase begins on August 25, 16 hours before closest approach to the planet, and runs through August 27, 28 hours after closest approach. Closest passes to Dione, Mimas, Saturn, Enceladus, Tethys, and Rhea, as well as to eight recently discovered unnamed moonlets of Saturn, will occur in this time span. To preserve a flight path beyond Saturn to Uranus, Voyager 2 will forego a close encounter with Titan. Voyager 2 will cross the ring plane only once, dipping below it nearly an hour after closest approach to Saturn. This late ring plane crossing will afford better views of the planet's northern hemisphere than obtained by Voyager 1, which dipped below the ring plane nearly 18 hours before closest approach and then rose above again about four hours after Saturn encounter.

Twenty minutes before closest approach to the planet, Voyager 2 will be 55,200 kilometers (34,300 miles) above the edge of the A-Ring – the closest approach to the ring plane itself. Voyager 2 will pass about 161,000 kilometers (100,000 miles) from the planet's southern hemisphere at 8:25 p.m. August 25 (Pacific Dayling Time), when the countdown clocks to Saturn encounter will all turn to 00:00:00. Signals from the spacecraft will travel 1 hour 26 minutes 35 seconds to reach earth.

Voyager 2's Saturn observations will continue in the **Post Encounter** phase from August 27 through September 28.

As the spacecraft leaves Saturn behind, it will fire its gas thrusters on September 29 to adjust its course for the next planet in its path, ringed Uranus. Voyager 2 will cruise for about 4-1/2 years, taking measurements in interplanetary space before becoming the first spacecraft from earth to explore Uranus, its rings, and its moons Ariel, Miranda, Oberon, Titania, and Umbriel.

Changes in Science Emphasis

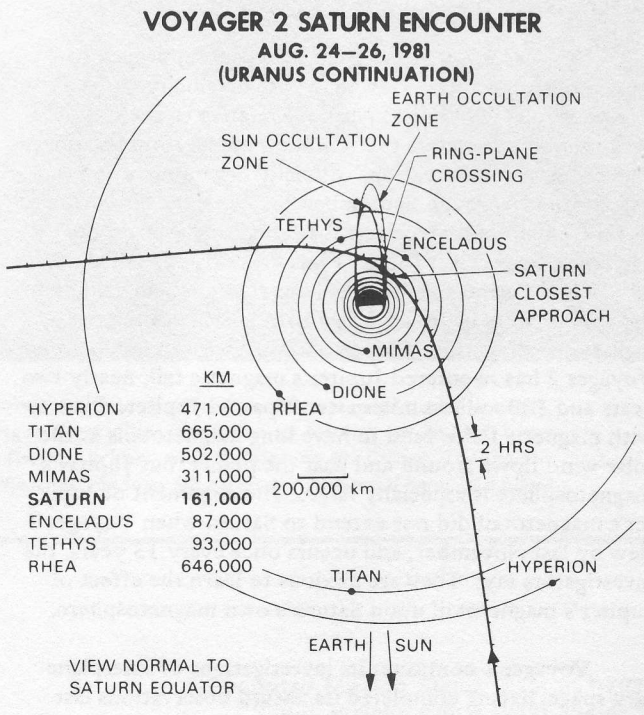
As a result of Voyager 1's spectacular findings last fall, mission planners have made many changes to the original tasks to be performed by Voyager 2. Because of Voyager 1's amazing findings last fall, Voyager 2's emphasis will be on the rings. The F-ring will be studied in detail to learn more about its structure, which appeared to be three interwoven elements in Voyager 1's photos. F-ring dynamics will also be studied closely. The non-circular, or eccentric, rings will also be scrutinized as scientists try to learn the causes of these peculiarities. The eccentricities may be related to gravitational resonances from the satellite Mimas, at some distance from the rings. Voyager 1 recorded 10 Megawatt electrical discharges in the rings, so Voyager 2's planetary radio astronomy receivers will be searching for additional evidence of these discharges, which are similar to lightning discharges here on earth. The photopolarimeter will track a star, Delta Scorpii, through the ring material. The varying brightness of the star will give an indication of ring density at various points.

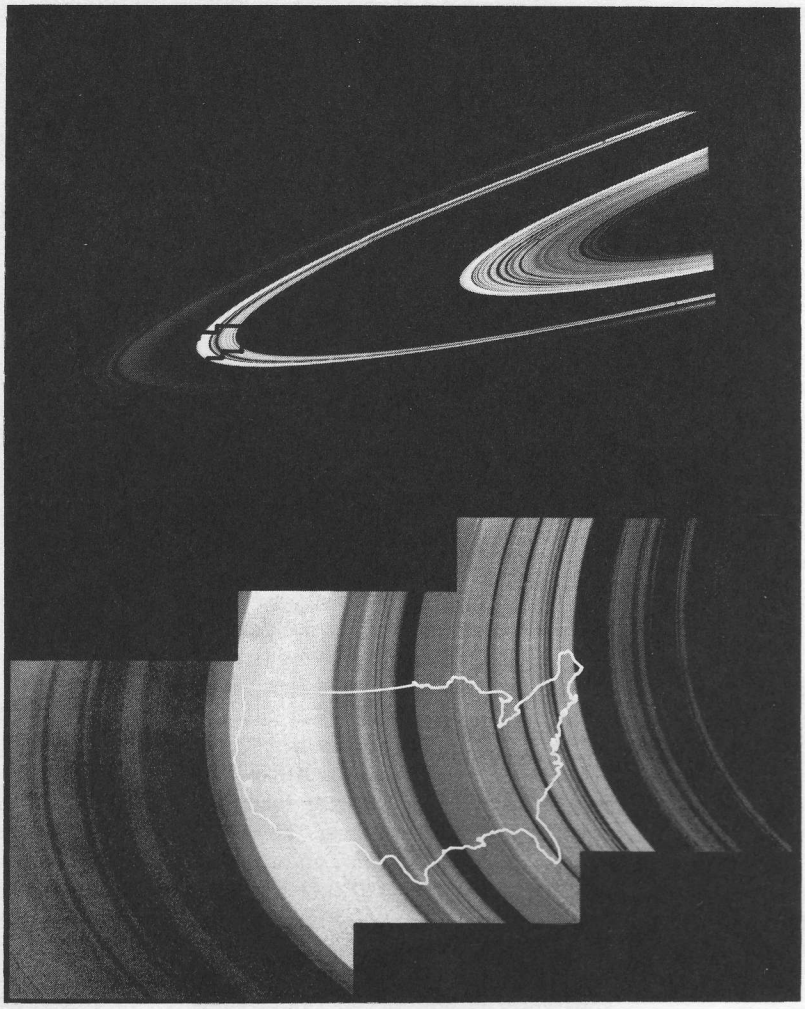
At the planet, Voyager 2 is expected to obtain better temperature measurements at various latitudes; better measurements of the rings, atmosphere and ionosphere using the radio; and better characterization of the auroras, which are seen in the ultraviolet.

Voyager 2 will obtain closer flybys of Iapetus, Hyperion, Enceladus, Tethys, and Phoebe. Enceladus is especially interesting since Voyager 1 photos showed little evidence of surface features, indicating there may be dynamic geological processes occurring. Voyager 2 will photograph Enceladus and Tethys with high resolution and also take measurements as these satellites eclipse the sun. Voyager 2's photopolarimeter is in good working order, so it will be able to look for aerosols on Titan, something Voyager 1 was unable to do. The "rocks", the tiny satellites near the planet, will also be studied in greater detail.

The "Rocks"

With the earth-based discoveries earlier this year of two more small moons of Saturn, the number of Saturnian moons has risen to 17. Satellites 10 through 17 are collectively (and affectionately) called "the rocks" because of their small sizes. (The nomenclature Satellite 10, etc., is used by the Voyager Project pending official confirmation and christening by the International Astronomical Union.) The satellites currently referred to as 10 and 11 share an orbit about 14,400 kilometers (8,900 miles) outside the outer edge of the A-Ring. Satellite 12 shares an orbit with the larger satellite Dione about 242,000 kilometers (151,100 miles) outside the A-Ring. Satellites 13 and 14 shepherd the F-Ring between them, while Satellite 15 orbits near the edge of the A-Ring. The two new rocks, Satellites 16 and 17, appear to share an orbit with Tethys, about 164,400 kilometers (102,000 miles) outside the A-Ring. One appears to "lead" Tethys in its orbit, and is about 10 to 20 miles in diameter, while the other satellite is smaller and trails Tethys. Tethys is the only satellite known that apparently has both leading and trailing satellites. Voyager 2's cameras will be targetted to each of these satellites, hoping to learn more about what they are made of, how they were made, and how they got where they are.





Voyager 1 took these photos of Saturn's rings and the Cassini Division last fall. A portion of the upper photo, indicated by the outline, is seen at a closer distance below. The outline of the United States gives an indication of the distances involved. In Earth-based pictures, the Cassini Divison, a 3500-kilometer region between the classical A- and B-Rings, appears empty. Voyager 1 found it to be full of individual ringlets, as seen here. Some of these ringlets are as wide as 800 kilometers. In this picture, the Cassini Division is the region from the dark area at about the Mississippi River on the overlaid map to the eastern tip of Maine. The wide bright ring overlaid by the Western states is the inner edge of the A-Ring.

Update

Voyager 2 is 61 days from its closest approach to Saturn on August 25. Travelling with a velocity of 56,310 kilometers (34,990 miles) per hour relative to the sun, it is 57.3 million kilometers (35.6 million miles) from the ringed planet. Saturn observations officially began on June 5, and will continue through September 28. With the exception of its failed main radio receiver, the failed capacitor in the backup radio receiver (both failures occurred in April 1978), and several smaller problems that are being studied, the spacecraft is in good health, with all science instruments operating. The plasma wave investigators report that Voyager 2 has re-entered Jupiter's magnetic tail, nearly two years and 300 million miles after it passed Jupiter. Planets with magnetic fields tend to have long magnetotails as the solar wind flows around and past the planet, but Jupiter's magnetosphere is especially large. The alignment of Jupiter's magnetotail did not extend to Saturn when Voyager 1 flew by last November, and occurs once every 13 years, the investigators say. They are anxious to learn the effect of Jupiter's magnetotail upon Saturn's own magnetosphere.

Voyager 1 continues its investigations of interplanetary space, having completed its Saturn observations last December.

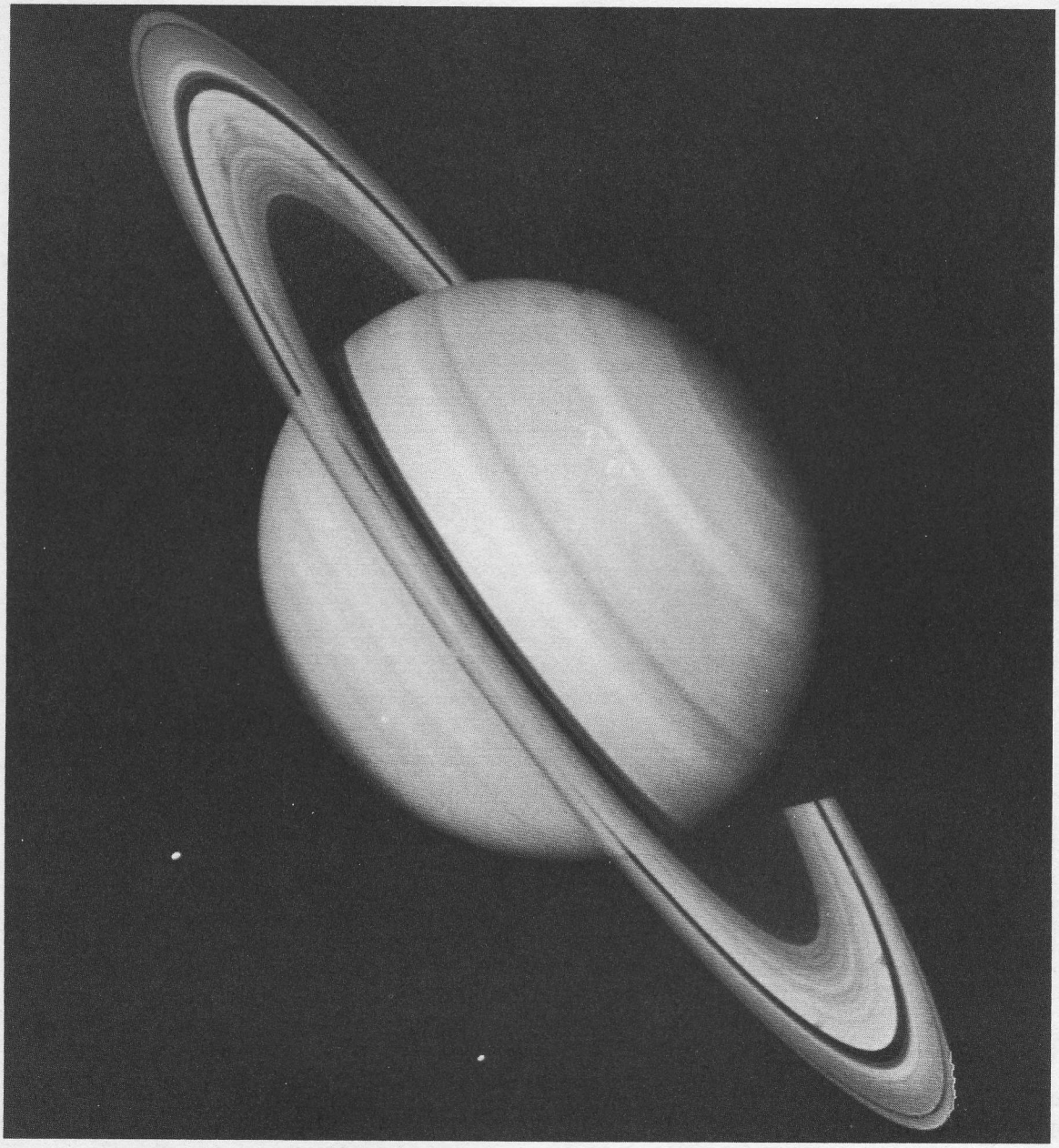
Voyager Team Garners Awards

The Voyager Team has received the National Aeronautic Association's prized Collier Trophy for 1980. The team has also won the Goddard Memorial Trophy of the National Space Club for the second year in a row. In a congratulatory letter on the occasion of the Collier Trophy, President Ronald Reagan remarked, "I welcome this opportunity to salute the remarkable accomplishments of the Voyager Mission Team . . . They have penetrated age-old mysteries and given us new knowledge of ancient worlds that can only challenge us to know more. No part of our government's programs electrifies the nation's spirit more than the space effort."

At a Voyager Awards Ceremony June 2, Dr. Hans Mark, nominee for the post of NASA Deputy Administrator, expressed the hope that "some centuries from now, when people look back at the year 1980 . . . they will remember the remarkable pictures of the different worlds first visited by the Voyagers . . ." and extended "hearty congratulations" on the achievements of the Voyager Team.

Voyager Bulletin

MISSION STATUS REPORT NO. 63 AUGUST 14, 1981



In this Voyager 2 photograph of Saturn taken July 21, 1981, from a range of 33.9 million kilometers (21 million miles), two bright, presumably convective cloud patterns are visible in the mid-northern hemisphere. Several dark spoke-like features can also be seen in the broad B-Ring (left of planet). The moons Rhea and Dione appear to the south and southeast of Saturn, respectively.

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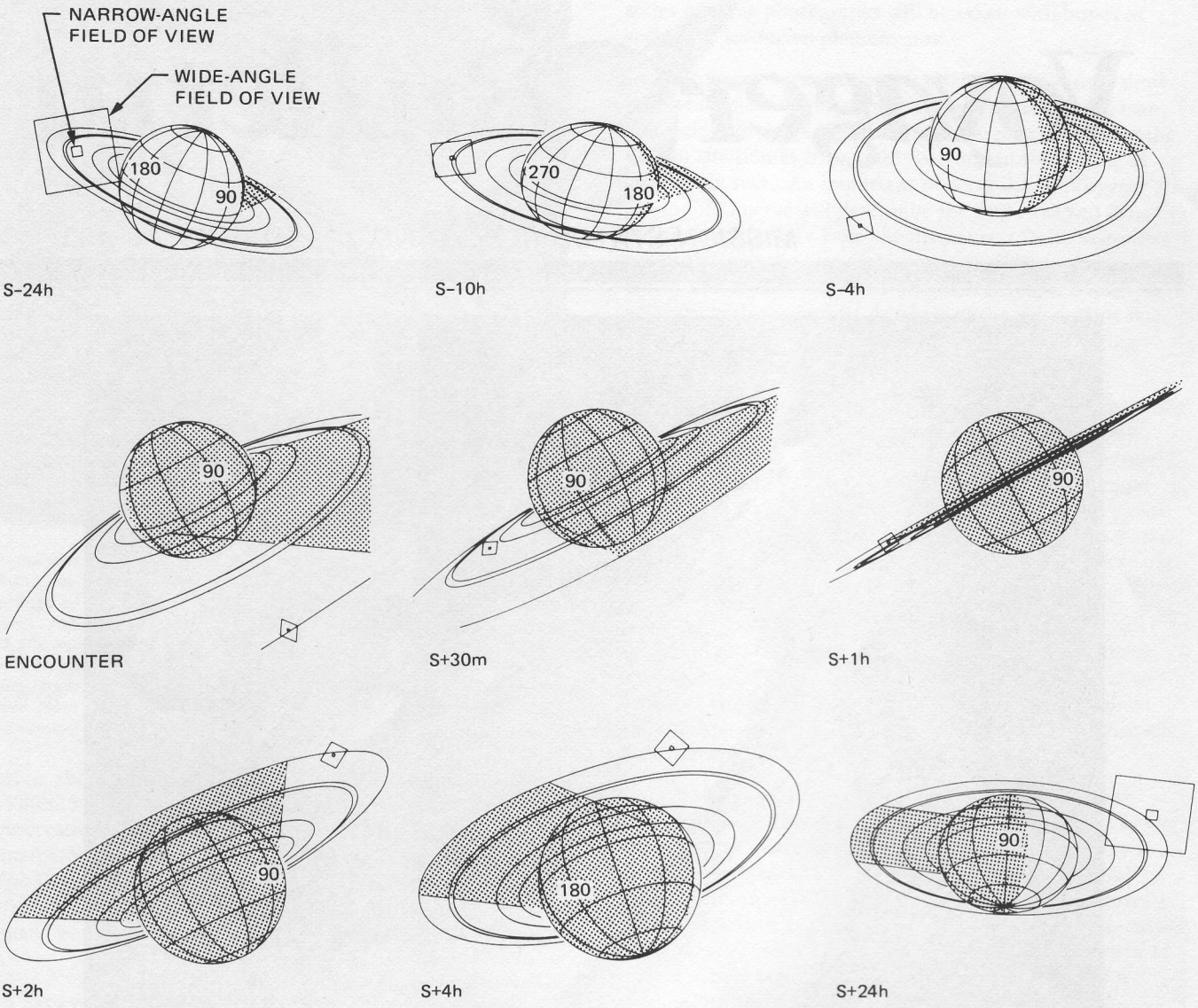
Voyager 2: Saturn Minus 12 Days

Recorded Mission Status (213) 354-7237
Status Bulletin Editor (213) 354-4438
Public Information Office (213) 354-5011



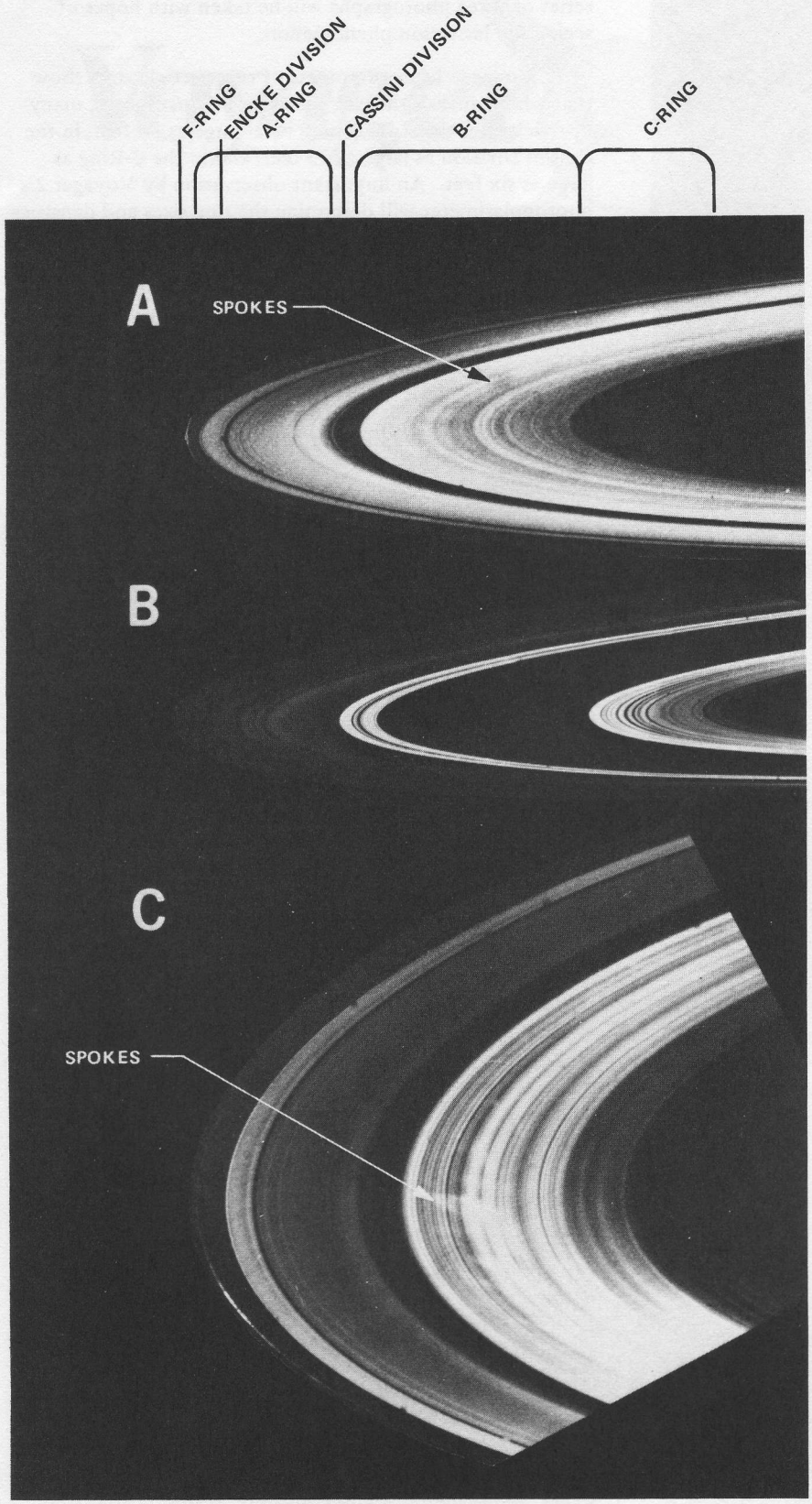
These computer-generated plots show how Voyager 2's view of the rings will change as the spacecraft flies past Saturn on August 24-26. The planet size is constant in these views to allow a comparison of Voyager's wide- and narrow-angle cameras' fields-of-view at various times (the locations of the fields-of-view shown here are not necessarily where the cameras will be pointing at these times but are shown only for size comparison; the longitudes given are also for reference only). One day before closest approach, Voyager 2 will still be above the ring plane on its inbound flight. The rings will continue to "open up" as the spacecraft draws near. At the moment of closest approach, only the west limb of the planet will be lit; the rest of the planet will be in shadow. Voyager 2 will dip below the ring plane nearly one hour after closest approach. The planet and rings will be in shadow. As it continues its outbound journey, Voyager 2 will remain below the ring plane, looking back on the planet as the rings once again "open up". All observations on the night side of the planet will be tape recorded for later playback to Earth, since the spacecraft will be out of radio communications with Earth for about 1-1/2 hours.

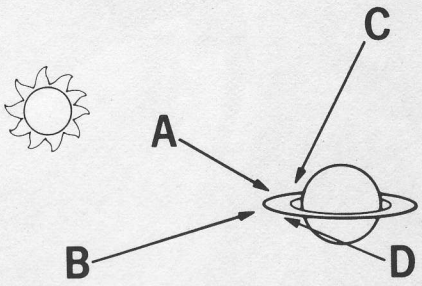
Mission Highlights

Voyager 2 is rapidly nearing its rendezvous with the Saturn system on August 25. As the spacecraft closes in on its target, all instruments are taking data on a regular basis. The Deep Space Network is providing round-the-clock tracking coverage.

Since Voyager 1's spectacular findings at the Saturn system last fall, Voyager 2 has been extensively reprogrammed to further explore many of the puzzling and interesting phenomena discovered by its twin.

Voyager 1 was expressly targeted for a close flyby of Saturn's largest satellite, haze-shrouded Titan. Voyager 2 is expressly targeted to continue on to the planets Uranus (January 1986) and Neptune (August 1989), so its observations of the Saturn system have been programmed around this requirement. Voyager 2 will not have a close flyby of Titan, but the photopolarimeter will look for aerosols in Titan's haze layers. Voyager 2 will come closer to Enceladus, Tethys, Hyperion, Iapetus, and Phoebe than did its twin. High-resolution photographs of Enceladus and Tethys will reveal more about their surfaces. Enceladus is highly reflective and appears to have few impact craters. Tethys has a 750-kilometer-long valley. Voyager 2 will also learn more about their thermal properties. Improved resolution photographs of Hyperion and Iapetus will also reveal more about the surfaces of these two icy satellites.
Voyager 1 passed too far from the outermost known Saturn satellite, tiny Phoebe, to photograph it, but Voyager 2 will photograph Phoebe on September 4. There is some specula-





Voyager 1 provided these perspectives of Saturn's rings in November 1980. The legend at top correlates to the ring features in the three mosaics, all of which are shown at the same scale. Voyager 2 will obtain pictures from angles similar to A and B, but not C. Instead, Voyager 2 will obtain pictures from below the ring plane, looking back at the sun from the unlit side (point D).

From point A, above the rings with the sun behind the spacecraft, the least dense areas appear dark since light passes through them. The densest areas appear brightest in this view because they contain the greatest number of particles to reflect sunlight. The B-Ring spokes appear dark in this view taken on Voyager 1's approach to the planet.

From point B, below the rings with the sun above and behind the spacecraft after ring plane crossing, detail can now be seen in the optically thin C-Ring and Cassini Division. Both of these features contain just enough material to scatter light but not enough to block its transmission to the unlit (southern) face of the rings. More optically thick regions, such as the A- and B-Rings, appear dark, as do true gaps (regions totally devoid of particles).

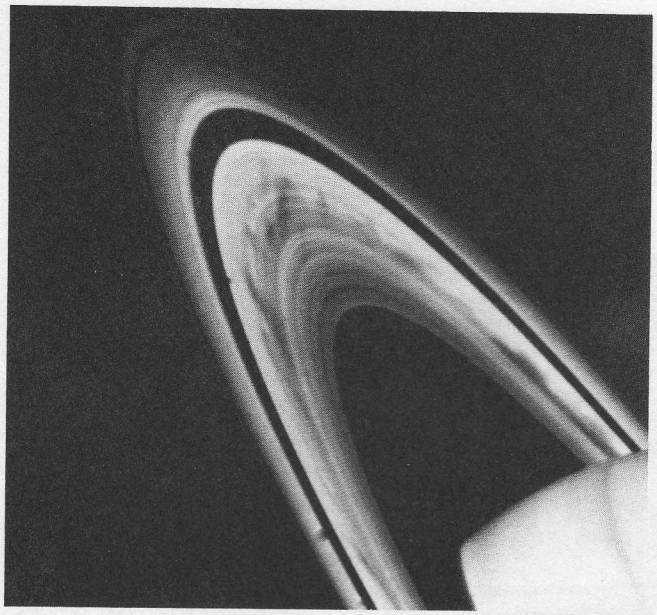
From point C, above the rings looking back toward the sun on the outbound leg, regions of the rings that are thought to have a significant amount of small (micrometer-sized) particles appear bright in forward scattered light. This includes the F-Ring, portions of the A- and B-Rings, and in particular, the B-Ring spokes.

tion that Phoebe, which orbits in the opposite direction of the other satellites, could be a captured asteroid.

Voyager 1 images of the surfaces of Mimas, Dione, and Rhea showed them to be heavily cratered but also showed evidence of crustal evolution – fractures and sparsely-cratered plains.

Many small moonlets have been discovered both from earth-based and spacecraft observations. Some of these small satellites appear to play an important role in ring dynamics. Without these moonlets, the rings might have long since dissipated into space, with nothing to keep them locked in orbit around the planet. Voyager 2 will target its cameras to capture the already-known moonlets, and will also look for other as yet undiscovered moonlets.

Several small satellites also share orbits with some of the larger satellites. 1980S6, about 160 kilometers diameter,



Prominent dark spokes are visible in the outer half of Saturn's broad B-Ring in this Voyager 2 photograph taken on August 3, 1981 from a range of about 22 million kilometers (14 million miles). The features appear as filamentary markings about 12,000 kilometers (7,500 miles) long, which rotate around the planet with the motion of particles in the rings. Because the sun is now illuminating the rings from a higher angle, Voyager 2's photographs reveal ring structure from a greater distance than that seen by Voyager 1 in its November 1980 encounter.

orbits about 60° ahead of Dione (1120 kilometers diameter). 1980S25 and 1980S13, discovered from ground-based observations, orbit near the L4 and L5 Lagrangian points (mathematical points of stability) in the orbit of Tethys. The L4 and L5 points lead and trail Tethys by 60°. About 30 to 40 kilometers in diameter, these tiny "trojans" trace small "tadpole"-shaped orbits along the orbit trail of Tethys.

Voyager 2 will concentrate many of its observations on Saturn's rings, a complex system of particles orbiting the planet in orderly (for the most part) fashion. The main ring system, from the D-Ring nearest the planet out to the F-Ring, stretches about 70,000 kilometers. The rings have been named in order of their discovery, and from the planet outwards, are referred to as the D, C, B, A, and F-Rings. Each of these rings has been found to contain many smaller ringlets, most of which are in circular orbits. A narrow G-Ring and a wide, diffuse E-Ring have also been located even farther from the planet. Voyager 2 will make special observations of two known "eccentric" or non-circular rings – one in the C-Ring and one in the Cassini Division between the A and B-Rings. The F-Ring appears to be composed of two or three elements which appear to intertwine, or to have clumpy regions. Voyager 2 will investigate this unusual ring by photographing it from several different angles to obtain pseudo-stereo images. Spokelike features extending radially across a section of the B-Ring will also be scrutinized to learn more about their dynamics – why do they form, how long do they exist, are they related to the planet's magnetic field. A 13-hour series of photographs will be taken of the B-Ring spoke areas about 3 days before closest approach. The spokes are thought to be particles of fine dust electrostatically levitated above the main body of the dense B-Ring. Their dissipation is caused by more rapid rotation of their inner portions, causing the spokes to "stretch" and eventually break up. During ring plane crossing, when the rings can be imaged edge-on, a series of three photographs will be taken with hopes of seeing the levitation phenomenon.

Voyager 1 measurements of ring particle sizes show that while most of the ring particles are dust motes, many "particles" in the A-Ring may be as large as 30 feet; in the Cassini Division as large as 25 feet; and in the C-Ring as large as six feet. An important observation by Voyager 2's photopolarimeter will determine the ring sizes and densities by tracking starlight from the distant star Delta Scorpii as it passes through the ring material on the way to the spacecraft. The intensity of the starlight reaching the spacecraft will vary with the optical densities of the rings. This star occultation measurement will stretch from the D-Ring nearest the planet all the way to the F-Ring.

Voyager 1 discovered an auroral ring at Saturn's north pole, similar to the auroras caused at Earth's poles by particles spiralling in along magnetic field lines. Voyager 2 will track the limb (edge) of the planet against the night sky, studying aurora-like emissions at lower latitudes (also first observed by Voyager 1). The interrelationship of the magnetic field lines, the ring particles, and these ultraviolet emissions may be very complex.

At Saturn, Voyager 2's infrared spectrometer will study the planet at various latitudes to learn more about its temperature balance. The spacecraft's radio signal will provide better measurements of the planet's atmosphere and ionosphere as the signal passes more vertically through these atmospheric levels than did Voyager 1's signal.

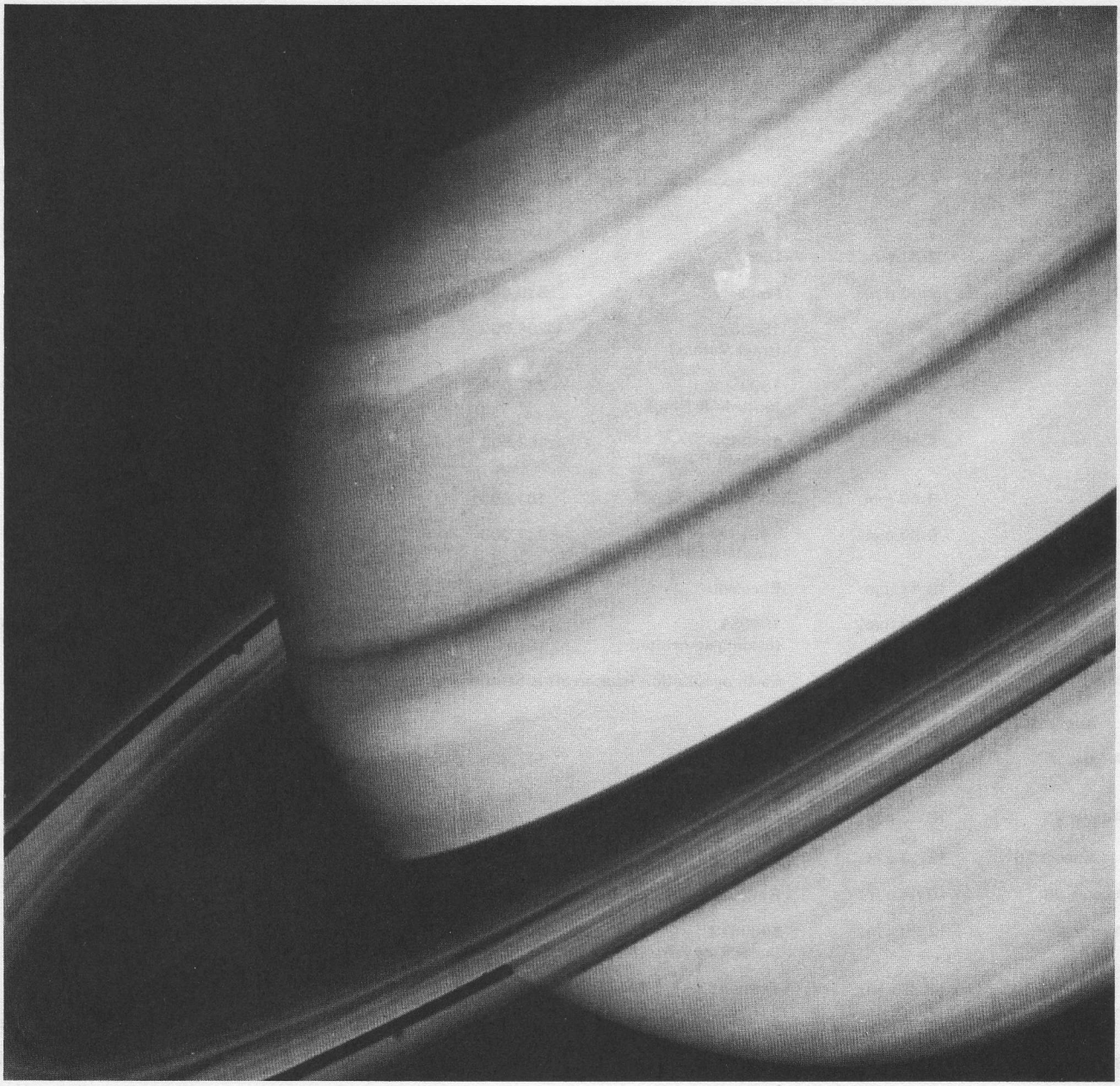
Both Voyagers carry six instruments designed to study interplanetary and interstellar space, magnetic fields, and planetary magnetospheres which trap particles from interplanetary space. Voyager 2 will maneuver several times within the Saturn system to allow these instruments to sample Saturn's magnetosphere. During these maneuvers, the spacecraft will be out of communication with Earth as the antenna is pointed away from Earth. Voyager 2 is expected to cross Saturn's bowshock in the early morning of August 24 (GMT). The bowshock marks the entry into space dominated by Saturn rather than by the sun. Particles streaming from the solar wind at supersonic speeds suddenly go subsonic at the bowshock. Voyager 1 reported re-entering Jupiter's magnetic tail earlier this year, indicating that the tail is extremely long and "flaps" back and forth in the solar wind like an enormous "tattered" wind sock. Planetary tails are measured by the absence of solar plasma and the presence of trapped plasmas. Jupiter's magneto-tail may possibly have swept across Saturn several times earlier this year. Evidence of these crossings may be apparent in Voyager 2's measurements of Saturn's interesting magnetic environment.

The fields and particles instruments include high- and low-field magnetometers as well as instruments to measure low-energy charged particles, cosmic rays, plasma, plasma waves, and planetary radio emissions. Radio bursts from Saturn allowed Voyager 1's planetary radio astronomy experiment to determine Saturn's rotation rate to be 10 hours 39.4 minutes.

On August 18, Voyager 2's flight path will be adjusted one last time before Saturn. The next trajectory correction, on September 29, will set the course for Uranus. Voyager 2's observations of Saturn this month will be the last photos we will receive from another planet until Voyager 2 approaches Uranus in late 1985.

Voyager Bulletin

MISSION STATUS REPORT NO. 64 AUGUST 20, 1981



Evidence of large-scale cloud systems centered at about 40-41°N are visible in this Voyager 2 image taken August 12, 1981 from about 13.9 million kilometers (the resolution is about 130 km). The bright cloud is a large-scale storm which moves in an easterly wind. To the west of this cloud are several light and dark clouds. The "ribbon-like" feature in the white band marks the high speed jet at about 47°N where the westerly wind speeds are about 150 meters per second.

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Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Voyager 2: Saturn Minus 6 Days

Recorded Mission Status (213) 354-7237
Status Bulletin Editor (213) 354-4438
Public Information Office (213) 354-5011

SUMMARY OF ENCOUNTER HIGHLIGHTS AND CLOSEST APPROACHES

The fields and particles instruments are making continuous observations throughout the encounter phases.

Date	Time[a]	Event[b]	Voyager 2 Distance[c] (km)	Voyager 2 Resolution[d] (km/1p)	Voyager 1 Distance[c] (km)	Voyager 1 Resolution[d] (km/1p)
August 18		Trajectory correction maneuver				
August 22	7:56 a.m.	Iapetus	910,000	17	2,470,000	49
August 24	7:53 p.m.	Hyperion	470,000	8.9	880,440	84
August 25	4:04 a.m.	Titan	665,000	12	6,490	1.3
	5:31 p.m.	1980S6 (Dione B)	318,000	7.6	230,000	
	6:06 p.m. to 8:26 p.m.	Star occultation (Delta Scorpii) by rings				
	7:31 p.m.	Dione	502,000	12	161,520	3
	9:00 p.m.	Mimas	310,000	5.8	88,440	4
	9:00 p.m.	1980S25 (trails Tethys)	284,000	4.6	Existence unknown then	
	9:35 p.m.	1980S28 (outside A-Ring)	287,000	6.8	219,000	13.4
	9:45 p.m.	1980S26 (outside F-Ring)	107,000		270,000	111
	9:50 p.m.	SATURN	101,000[c]		125,000[c]	
	9:59 p.m.	1980S27 (inside F-Ring)	247,000		300,000	98
	10:11 p.m.	Enceladus	87,000	1.6	202,040	11
	10:20 p.m.	1980S1 (leading co-orbital)	223,000	6.9	297,000	6.3
August 25 to August 26	10:26 p.m. to 12:01 a.m.	Earth occultation (spacecraft is behind planet, no communication with Earth)				
August 25	10:32 p.m.	1980S3 (trailing co-orbital)	147,000	6.5	121,000	3.3
August 25 to August 26	10:32 p.m. to 12:10 a.m.	Sun occultation				
August 25	10:44 p.m.	Ring plane crossing outbound and descending				
August 26	12:28 a.m.	1980S13 (leads Tethys)	154,000	12.2	Existence unknown then	
	12:38 a.m.	Tethys	93,000	5.4	415,670	25
	12:55 a.m.	Rhea	645,000	16	73,980	1.3
September 4	7:59 p.m.	Phoebe	2,080,000	38	12,537,000	No pictures

[a] Times are Earth-receipt of signal, Pacific Daylight Time. Events at the spacecraft occur about 1 hour 26 minutes 35 seconds prior to the times listed above (one-way light time, with radio signals travelling at the speed of light).

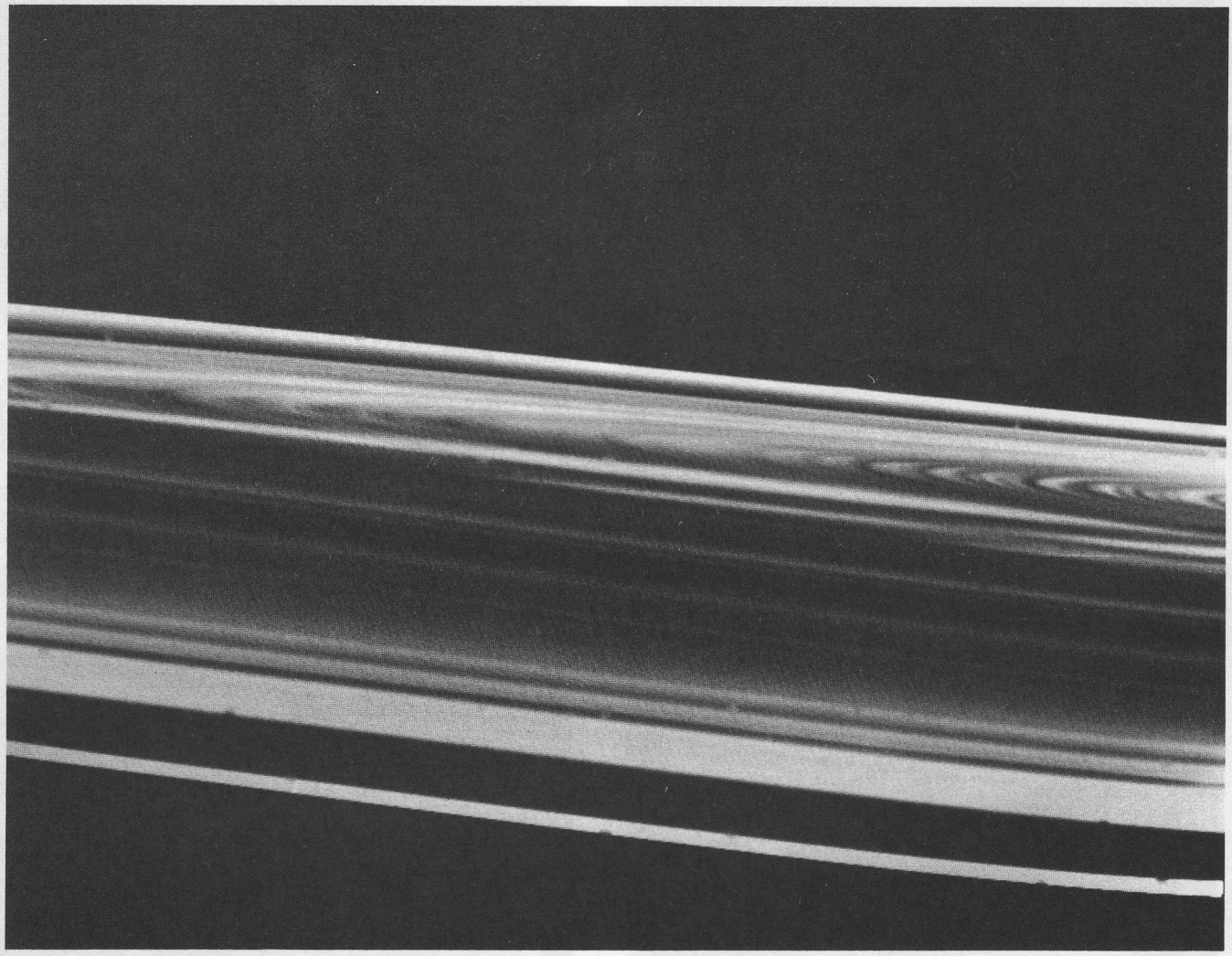
[b] Names indicate closest approach to that body.

[c] Except for Saturn, closest approach distances are from the center of the body. Closest approach to Saturn is given from the cloudtops.

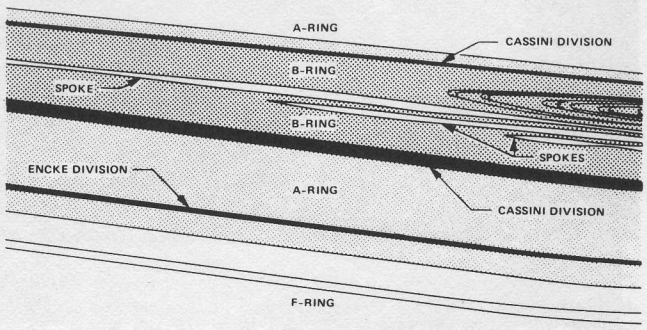
[d] Best resolution; best pictures are not necessarily taken at time of closest approaches due to lighting and other considerations.

Voyager Bulletin

MISSION STATUS REPORT NO. 65 SEPTEMBER 1, 1981



Moments before diving below Saturn's ring plane, Voyager 2 captured this extremely oblique view of the bright (northern) side of the complex rings. This angle highly magnifies features near the bottom of the picture and compresses features across to the other side of the west ansa (the western edge of the loop in the rings). The bright streaks in the B-Ring are the spokes in forward-scattered light. From this angle, one cannot ascertain any levitation of fine dust particles to form the spokes. 8/25/81, 103,000 km (64,000 mi)



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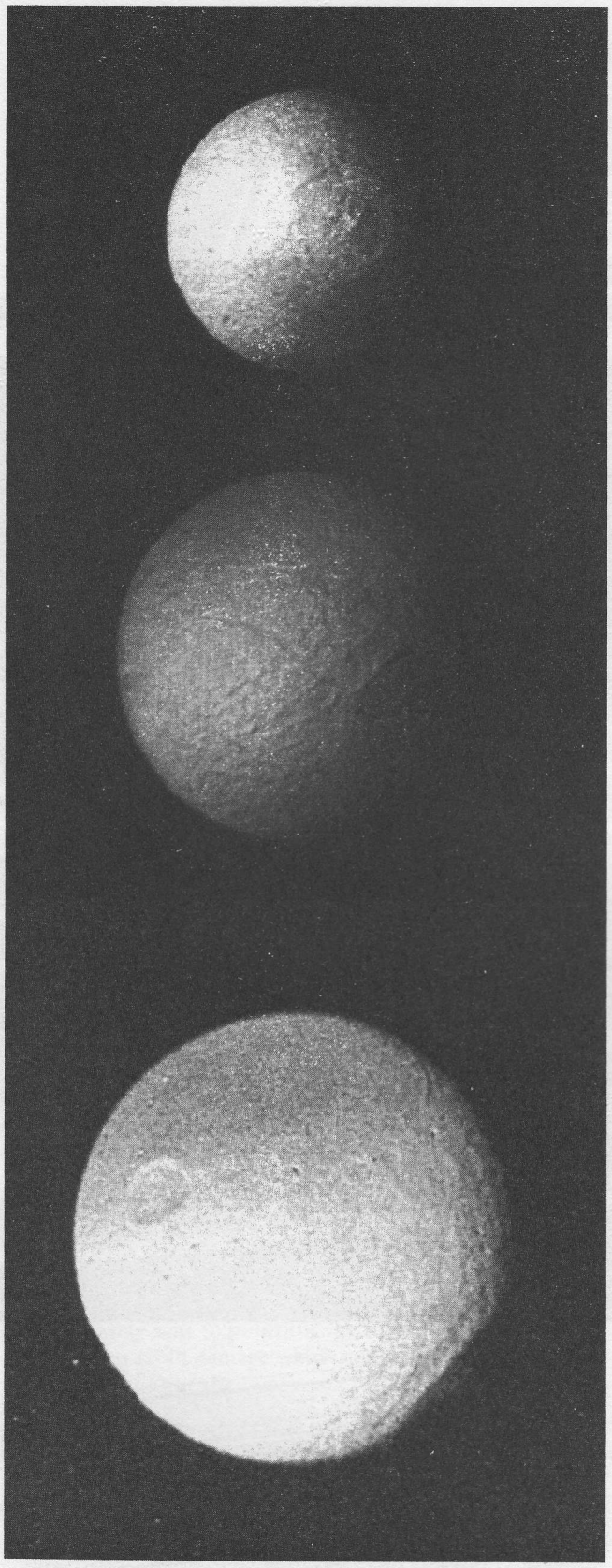
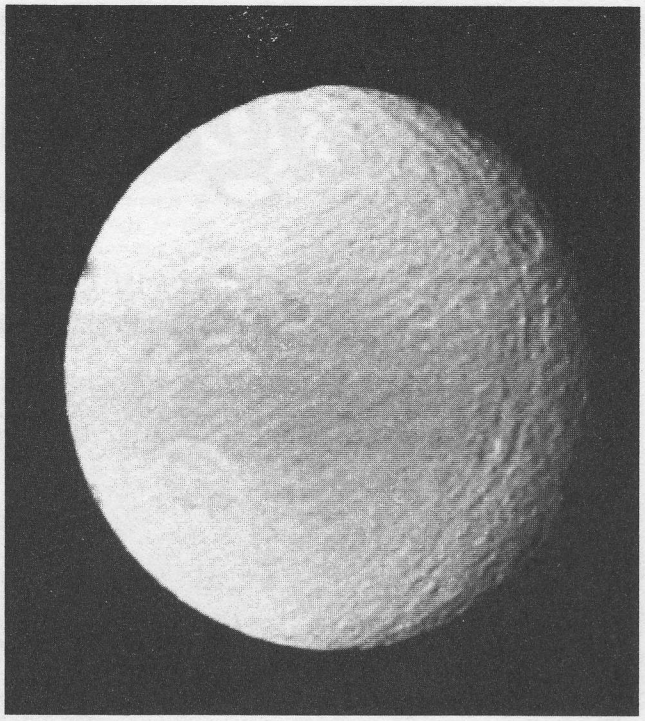
Voyager 2: Saturn Plus 7 Days

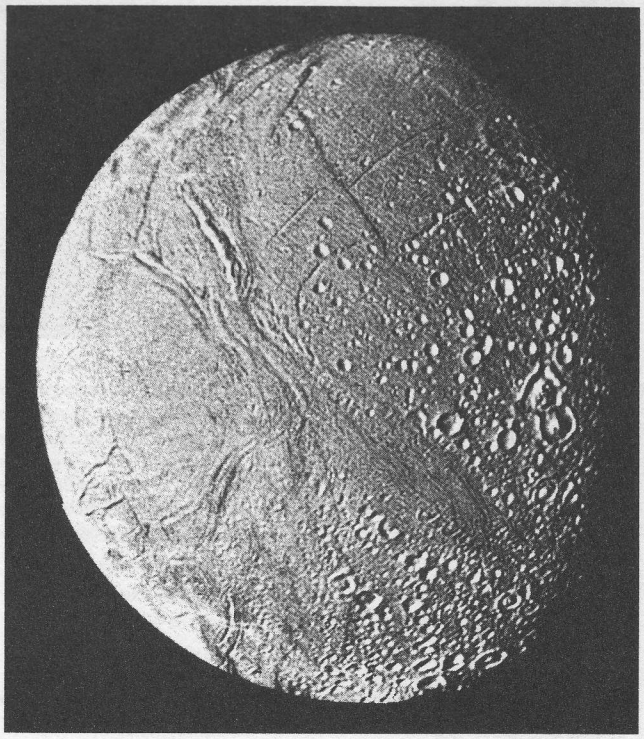
Recorded Mission Status (213) 354-7237
Status Bulletin Editor (213) 354-4438
Public Information Office (213) 354-5011



This series of Voyager 2 pictures of Tethys shows the satellite's distinctive large crater, 400 km (250 mi) in diameter, as it rotates toward the day/night terminator and limb (to the right). These images were obtained at four-hour intervals beginning late August 24 and ending early the next day. The remnant of a large impact, the crater has a central peak and several concentric rings. Some grooves radiating from the center may be formed of material thrown from the crater during the impact. The bottom frame, with the crater in profile, reveals that the crater floor has risen back to the spherical shape of the satellite, unlike the large crater seen on Tethys' sister moon Mimas.

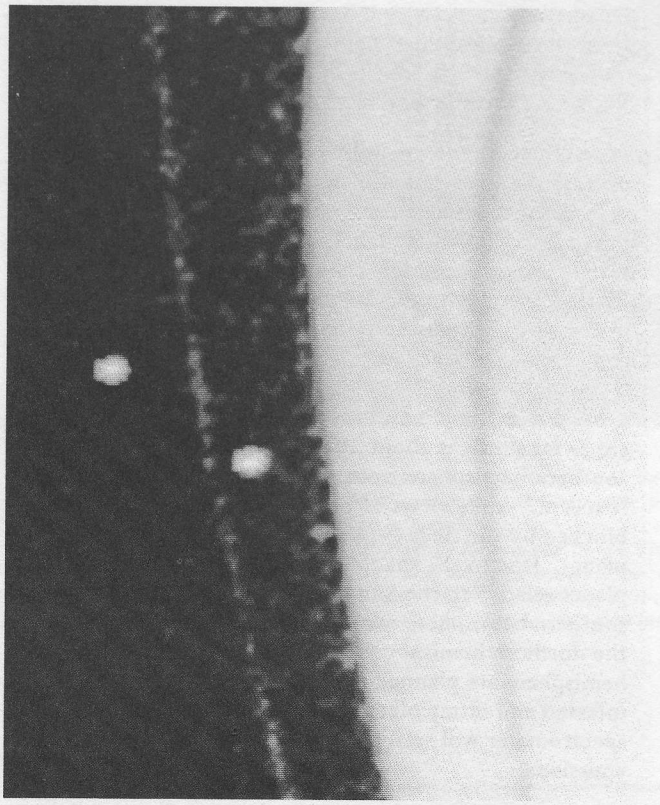


Tethys shows two distinct types of terrain – bright, densely cratered regions; and relatively dark, lightly cratered plains that extend in a broad belt across the satellite. The densely cratered terrain is believed to be part of the ancient crust of the satellite; the lightly cratered plains are thought to have been formed later by internal processes. Also clearly seen is a trough that runs parallel to the terminator (the day-night boundary, seen at right). This trough is an extension of the huge canyon system seen by Voyager 1 last fall. This system extends nearly two-thirds the distance around Tethys. 8/25/81 594,000 km (368,000 mi)

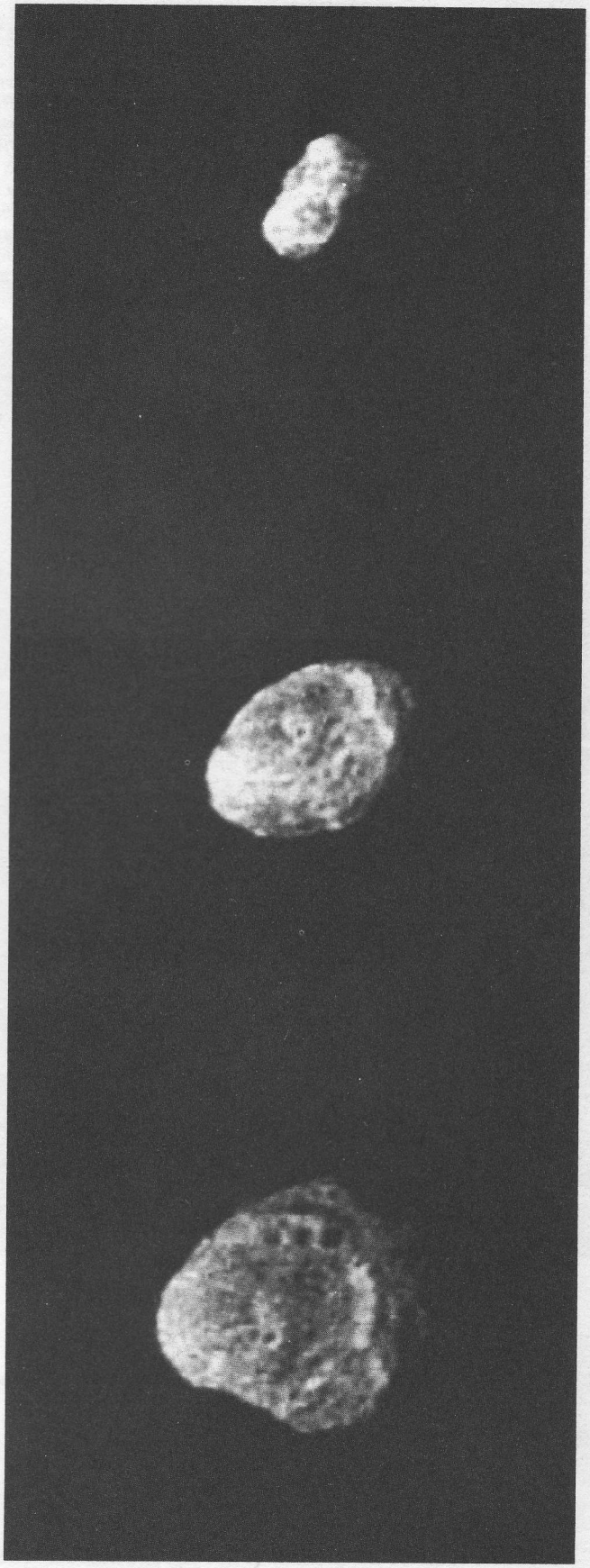


This high-resolution filtered mosaic shows surface detail on Enceladus. Enceladus resembles Jupiter's Galilean satellite Ganymede; however, Ganymede is about 10 times larger. Faintly visible here in "Saturnshine" is the hemisphere turned away from the sun. 8/25/81 119,000 km (74,000 mi)

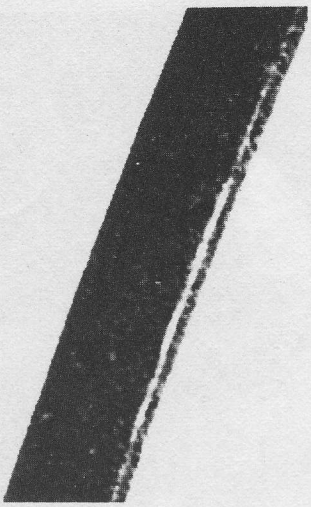
Iapetus, the outermost of Saturn's large satellites, shows features as small as 21 km (13 mi) across. This image has been processed to reveal as much detail as possible in the bright, icy regions of the northern trailing hemisphere. The number and forms of impact craters here appear similar to those of the heavily cratered surfaces of the inner icy satellites (such as Rhea and Mimas) photographed by Voyager 1. This similarity suggests an ancient crust dating back to the early history of the solar system. Iapetus is noteworthy for the very dark material (seen here in the lower and right-hand parts of the picture) that apparently covers the satellite's ice crust primarily on its leading hemisphere. Iapetus has a diameter of 1,450 km (900 mi). Voyager 2 passed about four times closer to the satellite than did Voyager 1 last fall. 8/22/81 1.1 million km (680,000 mi)



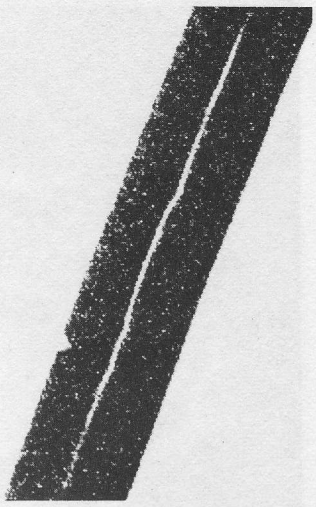
Herding the thin F-Ring between them, satellites 1980S27 (inner) and 1980S26 (outer) are about 1800 km (1100 mi) apart in this Voyager 2 image. Travelling slightly faster, the inside moon overtook the outer one about two hours later. This "lapping" occurs every 25 days. The A-Ring and Encke Division are to the right in this image, which was over-exposed to capture the faint F-Ring and its two shepherds. 8/15/81 10.5 million km (6.6 million mi)



These views of Hyperion show the changing aspect of the satellite as Voyager 2 closed in. Roughly 360 km by 210 km (220 mi by 130 mi) and shaped like a hamburger. Hyperion probably is not in a gravitationally stable position. Its surface is pock-marked with many meteorite-impact craters. It is possible that one of these impacts jostled Hyperion out of position and that the satellite will swing back gradually. 8/23/81 1.2 million km (740,000 mi), 8/24/81 700,000 km (430,000 mi), 8/24/81 500,000 km (310,000 mi).



Voyager 2's cameras discovered a new "kinky" ringlet inside the Encke gap in Saturn's A-Ring. Photopolarimeter data indicates additional structure within the gap. These pictures show the thin ringlet at two different positions, photographed near the time the spacecraft crossed the planet's ring-plane. Resolution is about 15 km (9 mi) in both frames. Here, the ringlet appears in two different positions: about midway in the gap in the right-hand image and near the inner edge of the gap at left. Scientists do not know if the kinky ring is eccentric, or off-center, or if perhaps there are several inner rings, with different components visible at different longitudes. The kinks, clearly visible on the right, appear to be more closely spaced than those seen in Saturn's outer F-Ring. (The fine white dots or "snow" in these pictures are artifacts of processing and are not individual moonlets. 8/25/81 700,000 km (435,000 mi)



Update

On September 4, ten days and 9.7 million kilometers (6 million miles) beyond Saturn, Voyager 2 will photograph tiny Phoebe, Saturn's outermost satellite. Although the images will be only a few pixels (picture elements) across in the narrow-angle camera's field-of-view, they should provide valuable information since Phoebe has never been photographed from such close range (2.08 million kilometers). Neither Pioneer 11 nor Voyager 1 passed close enough to photograph Phoebe, which may be a captured asteroid. Only 160 kilometers (100 miles) in diameter, it orbits nearly 13 million kilometers (8.1 million miles) from Saturn in a plane highly inclined to that of the rest of the Saturn system. It also orbits in the opposite direction from the rest of the satellites, and rotates asynchronously. All of the other Saturn satellites rotate synchronously; i.e., the same side always faces the planet. Phoebe pictures taken over a 24-hour period may be assembled into a time-lapse movie to learn more about its rotation rate, shape, and other characteristics. The photopolarimeter will also observe Phoebe.

Engineers continue to investigate the problem which caused the spacecraft's scan platform to stick on August 25 shortly after closest approach to the planet. The spacecraft was in the planet's shadow and out of communications with Earth when the platform stuck. The problem was discovered as the spacecraft emerged from behind the planet and resumed communications. Commands were immediately sent to point the instruments away from the Sun to avoid damage which could result from direct pointing at the Sun.

Four instruments – the wide- and narrow-angle cameras, the infrared and ultraviolet spectrometers, and the photopolarimeter – are mounted on the scan platform at the tip of a 7.5-foot boom which extends from the main body of the spacecraft. The platform moves in two directions: azimuth (side to side) and elevation (up and down). The problem affects movement in azimuth.

The cause of the problem is not yet understood. The scan platform stopped about 45 minutes after Voyager 2 crossed the ring plane, but this has not been directly related to the platform problem. The plasma wave instrument recorded an increase in the intensity of its data at the time of ring plane crossing, leading to speculation that the spacecraft was bombarded with dust particles which vaporized as they hit the spacecraft.

On August 28 the platform was successfully moved by ground command to point the instruments at Saturn once again. Early tests of the platform's movement showed that it **could** be moved, although its response was at times hesitant and slow. Its response has steadily improved.

The platform motion has been controlled entirely from the ground since the problem began. The Phoebe observations on September 4 will be the first platform motions commanded by the on-board computer sequence rather than by ground control since the problem occurred. As an engineering precaution, the range of azimuth positions required for the Phoebe observations has been satisfactorily explored by the platform in a diagnostic test. The platform's current position is favorable for Saturn and Phoebe observations, and is also a good position for the Uranus encounter in 1986, should the platform stick once more. With the successful flyby of Saturn, Uranus is now Voyager 2's prime target.

The computer sequence which would automatically operate the spacecraft for the month of September has been redesigned to include only "safe" activity. After assessing the problem, mission planners have been able to restore several important observations to the sequence, including Phoebe, imaging studies of the southern hemisphere, and ultraviolet studies of the south pole as well as several vital engineering calibrations.

On its inbound journey to Saturn, Voyager 2 could see as far south as about 40°S latitude. Now the entire southern hemisphere from equator to pole is visible to the spacecraft while views of the northern hemisphere are blocked by the rings (Voyager 2 is now below the ring plane). Due to the shadow of the rings and the tilt of the planet relative to the Sun, atmospheric dynamics in the southern hemisphere may be vastly different from those in the northern hemisphere. Observations of the southern hemisphere are planned with the imaging cameras, and the infrared and ultraviolet spectrometers. The ultraviolet spectrometer will scan the south pole to look for auroral emissions.

Although some valuable observations of the planet's dark side and southern hemisphere, the underside of the rings, and several satellites were lost, as well as one fields and particles maneuver, project scientists pronounce the encounter entirely successful due to the wealth of data received before the platform stuck.

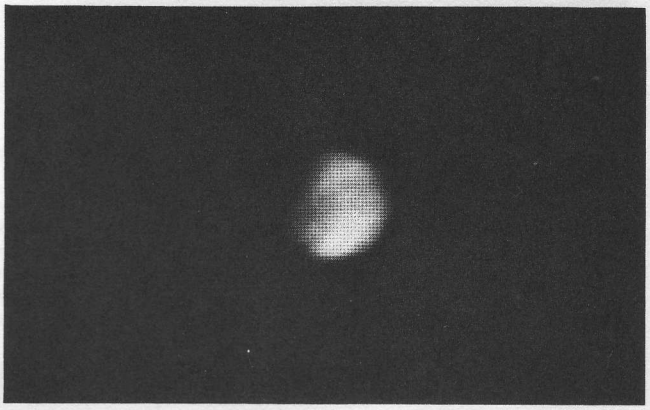
Voyager Bulletin

MISSION STATUS REPORT NO. 66 SEPTEMBER 23, 1981

Update

A trajectory correction maneuver on September 29 will refine Voyager 2's flight path to Uranus and target for an aimpoint to Neptune. The spacecraft's attitude control thrusters will burn hydrazine fuel for several hours to change the flight path. Several more trajectory corrections will be necessary before Voyager 2 flies past Uranus in January 1986.

Spacecraft activities affecting the scan platform will be severely curtailed for several months as analysis continues on the problem that affects platform motion in azimuth (side to side). Motion in elevation (up and down) is unrestricted. The platform will be operated only at low rates of speed and over a limited range from 180 to 270 degrees azimuth. This range gives a satisfactory set of positions for Saturn and Uranus observations. The problem that caused the platform to stick during the spacecraft's closest approach to Saturn is believed to be a physical problem related to such things as lubrication, worn gear mechanisms, and close clearances between the gears that operate the platform. Analysis and laboratory testing with a duplicate scan platform actuator will continue efforts to isolate the cause of the problem and to determine the best strategies for future use of the platform. Instruments aboard the platform include the wide- and narrow-angle cameras, the infrared interferometer spectrometer, the ultraviolet spectrometer, and the photopolarimeter.



Mounting evidence indicates that Phoebe, Saturn's outermost satellite, is almost certainly a captured asteroid and did not form in the original Saturn nebula as did Saturn's other satellites. Voyager 2's observations of Phoebe on September 4 showed that it is about 200 kilometers (120 miles) in diameter – about twice as large as earth-based observations had measured it to be. It is darker than any other of Saturn's satellites, with about five percent reflectivity. The rotation period, determined from Voyager 2 observations, is nine to ten hours. Phoebe is the only Saturnian satellite that does not always show the same face to Saturn. It orbits Saturn (every 550 days) in the ecliptic plane rather than in Saturn's equatorial plane as do the other Saturnian satellites. Its orbit is also retrograde – in the direction opposite to that of the other satellites. 9/4/81 2.2 million km (1.35 million mi)

Saturn Science Results

The Planet

Saturn has undergone several changes in the nine months between the two Voyager flybys. These atmospheric changes are subtle, however, and shorter-lived than at Jupiter, due both to the high wind velocities which tear apart storms and to the colder temperatures which cause color-producing particles to precipitate at lower levels in the atmosphere. Although Saturn's atmosphere appears much blander than Jupiter's, many of the same fierce weather patterns rage in its clouds.

Voyager 2 saw more detail in Saturn's atmosphere for several reasons. Portions of the haze which appeared to shroud the planet nine months ago when Voyager 1 flew by have lifted. Voyager 2's imaging cameras have slightly better vidicon tubes, resulting in improved picture resolution. And, based on Voyager 1's observations, Voyager 2 could be much more selective and precise about where it looked.

Color variations in Saturn's atmosphere are not as great as at Jupiter, probably due to differences in the mixing of chromophores which give color to gases. Indeed, from a distance, Saturn looks much like a butterball. However, upon closer inspection, and through different color filters, the real structure of the atmosphere becomes apparent. Saturn is banded, like Jupiter, but the bands cannot be so clearly defined as Jupiter's dark belts and light zones. In fact, Saturn's bands have little correlation with either wind velocities or temperature gradients. At Jupiter, the edges of belts and zones are generally high-speed jet streams flowing in opposing directions. Great wind shears lie between these jets. This apparently is not true at Saturn, where such high speed jet streams occur more often than

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Recorded Mission Status (213) 354-7237
Status Bulletin Editor (213) 354-4438
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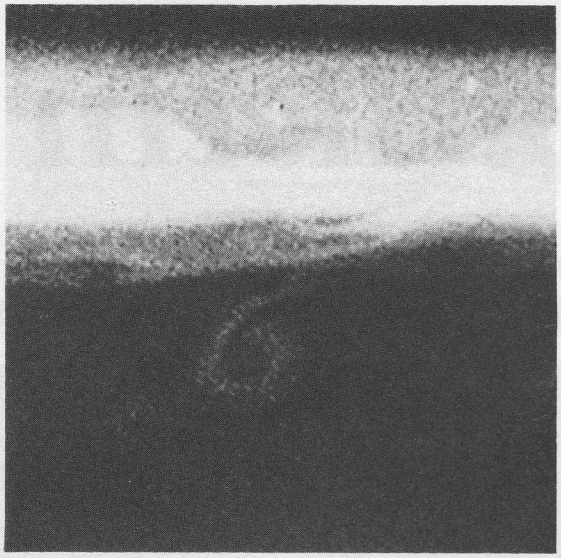
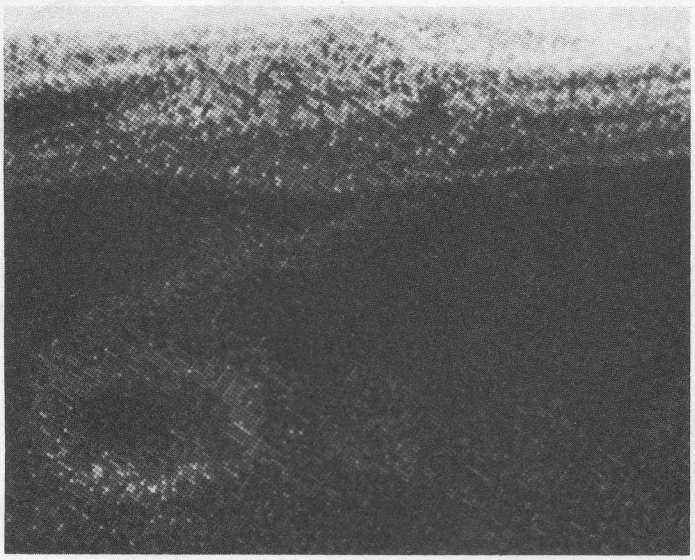
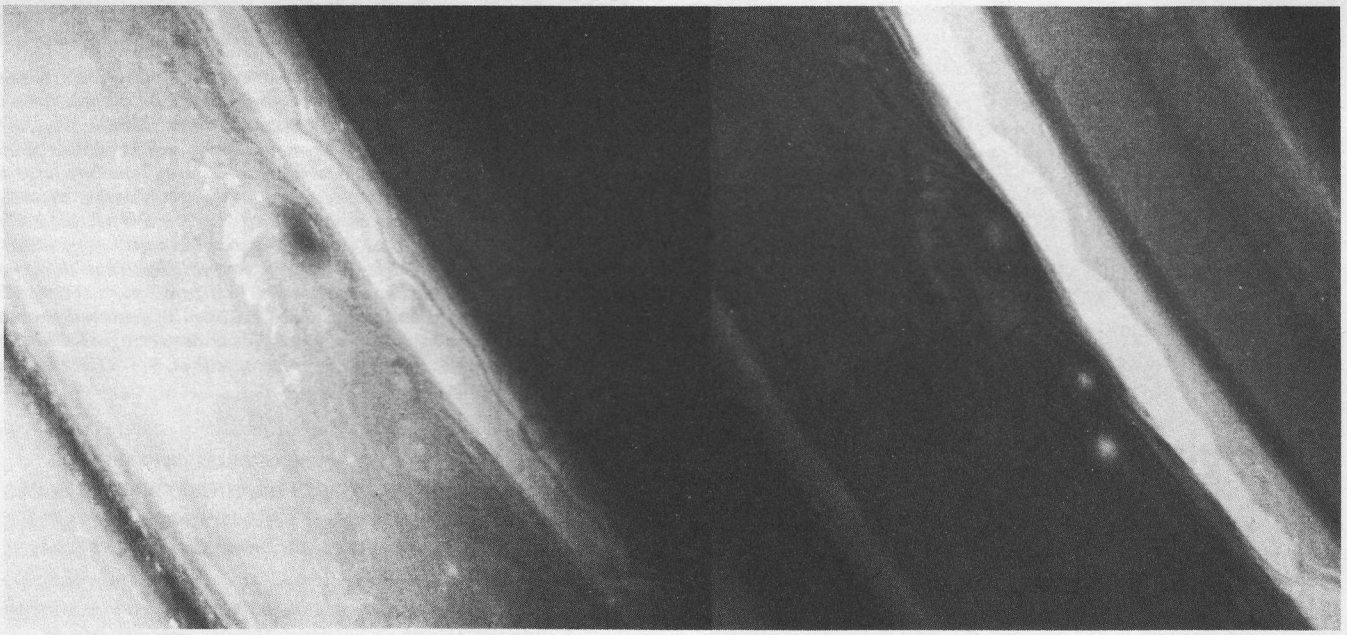




A strangely curled cloud in Saturn's northern mid-latitudes gradually unfolded as Voyager 2 observed it. At left, it is "corkscrew"-shaped and at right, 64 hours later, it has become more like a "6". It is attached by a thin ribbon of cloud to the bright white cloud region to the north where winds blow 130 meters per second (290 miles per hour). Also evident is a ribbon-like structure at 47°N latitude in the white cloud region.
(L) 8/16/81 9.3 million km (5.8 million mi)
(R) 8/20/81 6.4 million km (4 million mi)



These pictures show the same region of the planet, but the frame on the right was taken through a violet filter and the one on the left through a green filter. The violet image shows a bright band about 3,000 km (1,900 mi) wide north of three bright oval cloud systems. Two of these storms lose contrast in the green image and are barely visible. The third and largest feature, 3,000 km (1,900 mi) in diameter, is dark in the green and has a measured clockwise rotation. 8/19/81 7.1 million km (4.4 million mi)

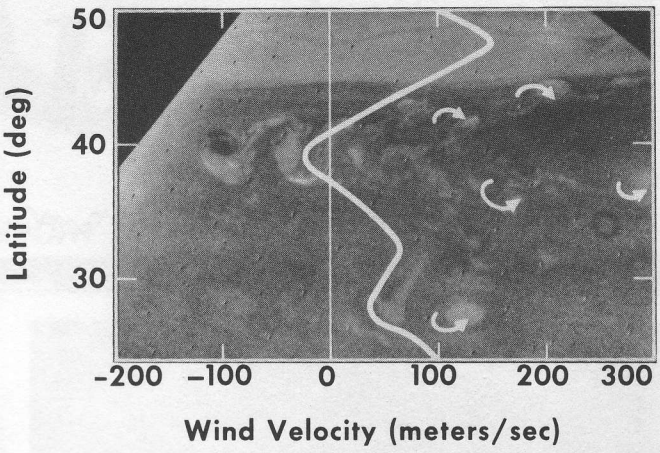
not in the middle of a band. (However, it is sometimes difficult to ascertain boundaries between Saturn's belts and zones since they appear differently depending on the color filter used to photograph them.) Between 35°N and 35°S latitude, Saturn's winds blow consistently eastward, with maximum speeds of at least 500 meters per second (1100 miles per hour) near the equator – four times the greatest winds on Jupiter. Few storm systems survive long due to the tremendous forces which drive these winds. Although Voyager 2 observed a gigantic storm system first seen by Voyager 1 last fall, storms such as Jupiter's centuries-old Great Red Spot and 40-year-old white ovals probably do not exist on Saturn.

The wind speeds are deduced from the time-lapse images taken by the spacecraft and are relative to the rotation rate of the bulk of Saturn's interior. This rate has been determined by the planetary radio astronomy experiment to be 10 hours 39 minutes 24 seconds.

Cloud vortices (small hurricanes), jet streams, and eddies are also evident at higher latitudes (up to 80°N) than at Jupiter (50°N and S). A train of vortices is apparent between 30° and 50°N.

For several days in late August, a large vortex in Saturn's northern mid-latitudes unfolded as Voyager 2 recorded its progress. Initially corkscrew-shaped, it became more like a "6" and eventually formed a closed loop over a period of seven rotations. Study of such events gives clues to the planet's atmospheric dynamics.

Twice as far from the Sun as is Jupiter, Saturn is much colder, with temperatures of 80 to 95 Kelvin at the cloudtops (where the atmospheric pressure is one-fourth Earth's). However, Saturn still radiates almost 2.5 times as much energy as it receives from the Sun. Eighty-nine percent of Saturn's atmospheric mass is hydrogen, while most of the remaining eleven percent is helium. This is much less helium that has been measured in Jupiter's atmosphere (19%), and lends credence to the theory that Saturn's helium sinks toward the center of the planet, providing a source of heat. Traces of ammonia, phosphine, methane, ethane, acetylene, methylacetylene, and propane have also been detected in Saturn's atmosphere.



A westward-flowing wind current appears to drive a wedge through a train of vortices (small hurricanes) at about 40°N latitude. The wind velocities are plotted on a photograph of this area and show the westward flow with obvious eastward streams above and below. As the vortice separates, smaller cyclones are formed. Those to the north rotate clockwise; those to the south rotate counterclockwise. This is one of the many interesting phenomena observed by Voyager 2.

The Rings

To say that Saturn's ring system is complex is a gross understatement. There are no smooth, well-defined, uniform rings marching around the planet in an orderly fashion, as once perceived. Voyager 1's images in November 1980 showed there to be hundreds of rings, some of them not quite well-behaved. Voyager 2's photopolarimetric observations upped that figure to literally thousands, and perhaps tens of thousands, of ringlets, few of them well-behaved or orderly.

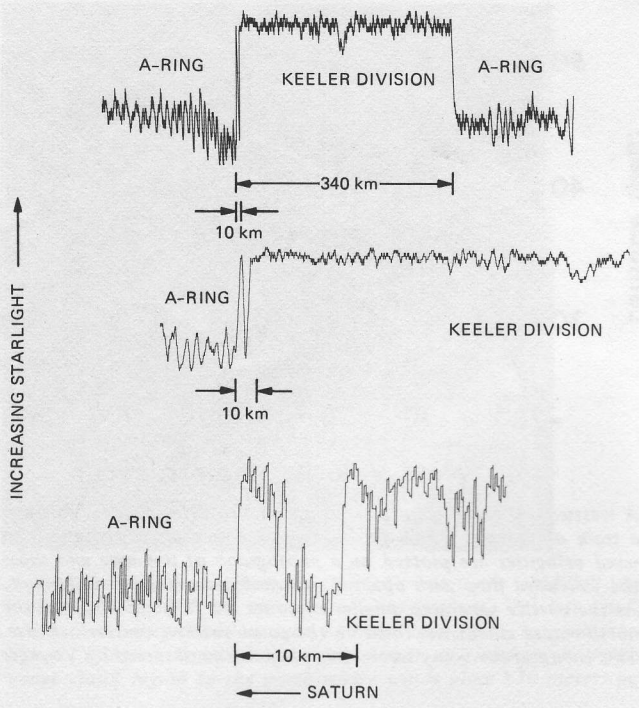
The main ring system extends from near the planet out to about 75,000 kilometers above the cloudtops, a vast sheet of icy debris varying in thickness, composition, and orbital characteristics. With resolution down to a city block – about 150 meters – the photopolarimeter's flood of data suddenly presents a new problem: what is a ring? what is the shoulder of one ring or the body of another? where does one ring end and another begin? It appears that some ringlets may narrow at the edges rather than having a uniform thickness (thus, they have so-called "shoulders"). Due to the viewing angles, none of Voyager's instruments determined with certainty the optical depth of a ringlet. Many of the ringlets are non-circular, indicating that structure changes rapidly, perhaps continuously, in the rings.

Several theories of the rings' stability have developed and were tested by Voyager 2's observations. Some mechanism is holding the ring particles in orbit around the planet; otherwise they would have escaped into space long ago. One theory supposes that the ring particles are in resonance with one of the larger satellites. Some of the larger "gaps" in the rings do indeed occur at distances corresponding to orbital resonances with Mimas (in a 2:1 resonance, the particles make two orbits for every one orbit by Mimas; Mimas also exerts a gravitational pull). A second theory proposes that small moonlets herd each ringlet. To test this theory, the imaging cameras searched the rings for evidence of such small moonlets, but none were found beyond those already known to shepherd the F-Ring. A third theory proposes density waves in the ring particles and some evidence of such waves is seen in Voyager data. A fourth theory involves collisions between the ring particles themselves. Relatively hard objects would ricochet off one another with some force, and would be less likely to stay in well-defined orbits. However, softer ice that has been banging around for billions of years will barely rebound, and in fact may shatter upon impact.

Voyager 2 re-verified the existence of the G- and D-Rings and photographed both of these plus the A, B, C, and F-Rings. The E-Ring was detected by the fields and particles instruments. Using the spacecraft's radio to determine particle sizes as the signal passed through the rings, analysts conclude the average particle sizes in the A-Ring are 10 meters (33 feet); in the outer Cassini Division 8 meters (26 feet); and in the C-Ring 2 meters (6.5 feet). Obviously, a "particle" can be anything from a dust speck to a very large boulder of ice.

Color differences within the major rings imply differences in composition, particle sizes, or both. Color-enhanced images of the C- and B-Ring show that some tiny ringlets within the C-Ring may have some compositional similarities to the B-Ring.

The mysterious finger-like structures in the B-Ring received a great deal of attention from Voyager 2, including some special ring plane crossing photographs and a series of time-lapse movies to study their formation and lifespans. These spokes form over very short time periods (minutes), primarily near the point where the ring particles emerge from Saturn's shadow. Most dissipate before completing a single orbit of the planet, but some remnants do persist and other spokes form on top of them. The spokes form radially; i.e., they extend outward from the planet like spokes in a wagon wheel, and they are seen on both faces of the rings, north and south (illuminated and unilluminated). (However, the features on the unlit side could possibly be shadows of spokes.) One theory proposes that the spokes are electrostatically-levitated particles of fine dust lifted above the plane of the rest of the B-Ring by Saturn's magnetic field lines which pass through the B-Ring in the spokes region. Three pictures were taken during ring plane crossing, when the rings could be viewed nearly edge-on, in hopes of seeing this phenomenon. The most spectacular of these pictures was 1/2 degree above the plane. No evidence of particle levitation could be seen from any of these pictures, however.

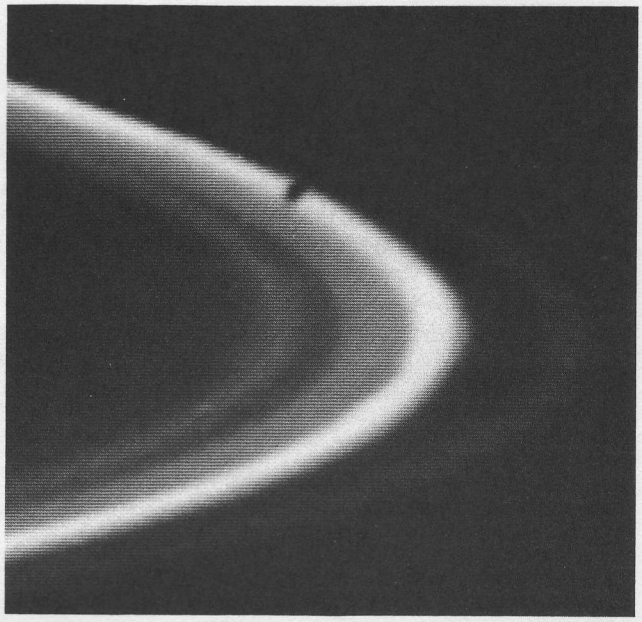


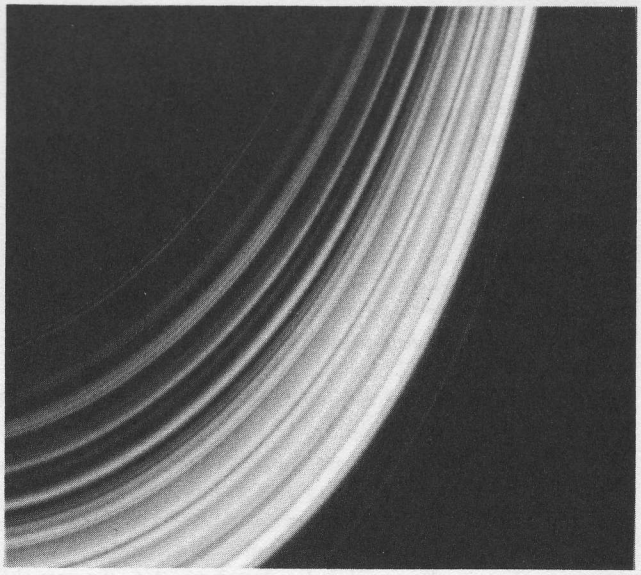
The high resolution of Voyager 2's photopolarimeter revealed ringlets that are undetectable by the cameras or radio system. These three plots show increasing resolution of an area including the Keeler (Encke) Division and the edges of the A-Ring. The amount of starlight (from the distant star Delta Scorpii) passing through the rings is plotted as a single line of varying brightness. Peaks in the curve indicate areas where there is little material to block the passage of starlight, while dips in the curve indicate areas where starlight is blocked by material. The Keeler Division is a relatively empty gap and therefore is seen as a peak in the top plot. The dip in the Keeler Division is probably the "kinky" ringlet photographed by Voyager 2's camera. With increasing resolution (moving down from the top plot), a feature at the inner boundary between the A-Ring and Keeler Division becomes apparent. This feature is believed to be a ringlet.

Voyager 1 detected lightning-like electrical discharges near the planet, with a periodicity of 10 hours 10 minutes, leading to speculation that these were occurring not in the planet's atmosphere but in the rings. During ring plane crossing, the plasma wave's radio receiver noted an enormous increase in the intensity of its signal, and the plasma wave investigators believe this indicates ionization of tiny dust particles hitting the spacecraft. The dust particles are not believed to have been sufficient to damage the spacecraft in any way, however.

The gap in the outer edge of the A-Ring known as the Encke Division may be renamed the Keeler Division in recognition of its probable discoverer. The Working Group on Planetary System Nomenclature of the International Astronomical Union (IAF) has been advised of the likelihood that James E. Keeler of Lick Observatory really saw this division in early 1888 (perhaps earlier) with a 90-cm refractor telescope. Until now, the discovery has been attributed to Johann Franz Encke, of the Berlin Observatory, who reported a shading in the A-Ring in 1837. It now seems unlikely that Encke, using a 22-cm telescope, could have seen a gap as small as this, and was seeing another feature. He reported a shading one-third the distance from the inner ring to the outer. In *The Astronomical Journal* (Vol. 8, page 175, 1889), Keeler reported seeing (with 400 power) the Encke shading on the outer A-Ring at about one-third its width from the outer edge. With a lens power of 1500, he reported seeing the inner shading and a division near the edge of the A-Ring about one-sixth the width of the ring from its outer edge. This is the location of the gap that has been known as the Encke Division. The issue will be discussed at the next IAU meeting.

At least four distinct components of Saturn's F-Ring are resolved in this edge-on image taken by Voyager 2's camera just prior to ring plane crossing. The camera resolution is about 10 km. The photopolarimeter, with a resolution of one city block, shows even more F-Ring components. Nearly 25 degrees of the ring are visible here. 8/26/81 103,000 km (64,000 mi)





As Voyager 2 passed over Saturn's rings, the photopolarimeter measured the intensity of light passing through the rings from the distant star Delta Scorpii and recorded the amount of starlight blocked or transmitted – an indication of the presence or absence of ring material. This picture of an area of the F-Ring was constructed with the aid of a computer graphics system by showing the recorded starlight intensity as a single line of varying brightness and then sweeping that line in an arc to achieve the two-dimensional effect. The perspective is from the Saturn side and slightly above the ring plane. Multiple "ministrands" can be seen in this area, which the imaging cameras recorded as the brightest strand in the F-Ring. From the inner to the outer ministrands, the distance here is approximately 70 kilometers (45 miles) and the resolution is 500 meters (550 yards).

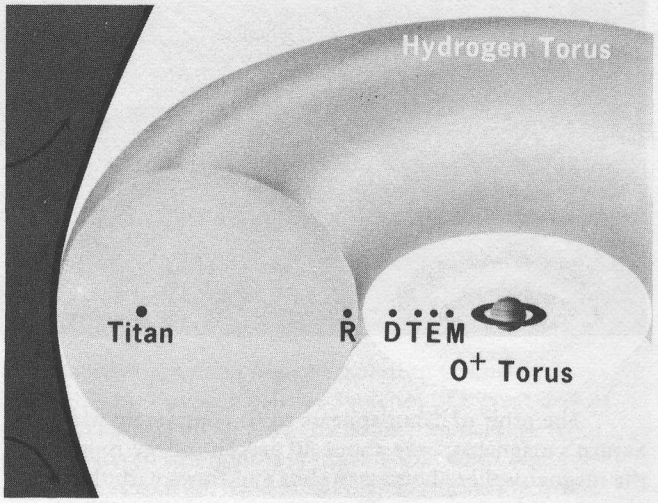
Voyager Bulletin

MISSION STATUS REPORT NO. 67 OCTOBER 12, 1981

Update

Voyager 2 has completed nearly half of its journey to Uranus, measured from launch on August 20, 1977 to Uranus closest approach on January 24, 1986. The four-year-old spacecraft, having travelled 2.4 billion kilometers (1.5 billion miles) continues to operate well. Analysis continues on its scan platform, which stuck shortly after closest approach to Saturn on August 25. The platform has been successfully maneuvered since then and prospects for a successful Uranus encounter are good. The problem appears to be related to lubrication, worn gear mechanisms, and close clearances between gears in the platform's azimuth actuator.

Voyager 1 continues to explore interplanetary space, having travelled over 2.7 billion kilometers (1.7 billion miles) since its launch on September 5, 1977. Voyager 1 hiccupped a little last week and presented flight controllers with an interesting computer glitch. The problem occurred on October 6 as controllers were changing the cruise data modes in one of six reprogrammable computers aboard the spacecraft. The flight data subsystem (FDS) computer program appeared to be stuck in a tight loop, ignoring commands from the computer command subsystem (CCS). An early effort to implement a new configuration command failed, but flight controllers were able to send "power on reset" commands on October 7, causing the FDS program to reset, and good data has been received since then. Two possible causes of the problem are being explored. The CCS may have sent a garbled command to the FDS, causing the FDS to begin sending meaningless data. The command would have been issued from the same CCS output unit that has caused several other problems aboard Voyager 1 since launch, including a maneuver abort. Another possibility is a failure of several words of FDS memory. Analysis of the problem continues.



Saturn and its satellites are surrounded by clouds of rarefied gases which form donut-shaped rings. A torus of neutral hydrogen extends from the magnetosheath at about 25 Saturn radii inward to about 7.5 Saturn radii (Saturn's radius is 60,330 km). Titan's atmosphere is believed to be the source of hydrogen in this torus. Nestled between the hydrogen torus and the planet is a smaller torus of ionized oxygen, believed to escape from Tethys and Dione. This torus extends from the inner edge of the hydrogen torus to about the orbit of Enceladus at about 3.9 Saturn radii. Its mass is about 40,000 tons, compared to 2 million tons for Jupiter's Io sulfur torus.

Saturn Science Results

The Magnetosphere

Voyager 2's trajectory took it on a wide arc through Saturn's magnetic field, exploring different regions and adding to the data of Pioneer 11 and Voyager 1.

All planets which have internally-originating magnetic fields also have magnetospheres. Magnetic field lines extending from pole to pole form a series of "shells" which rotate with the planet, sweeping charged particles around as well. When particles streaming from the sun in the solar wind meet the boundary of a planet's magnetic field, a bow shock occurs. Most of the solar particles are deflected and stream around the magnetosphere. Behind the bow shock, there is a region called the magnetosheath where particles stream at subsonic speeds. Finally, the magnetopause is the actual boundary between the magnetosheath and the magnetosphere. A magnetic tail is formed as solar wind particles stream past the planet and regroup. This magnetic tail may be of hundreds of millions of kilometers long at Saturn. Jupiter's magnetic tail may be half a billion miles long, extending as far as Saturn and blowing in the solar wind like a tattered wind sock.

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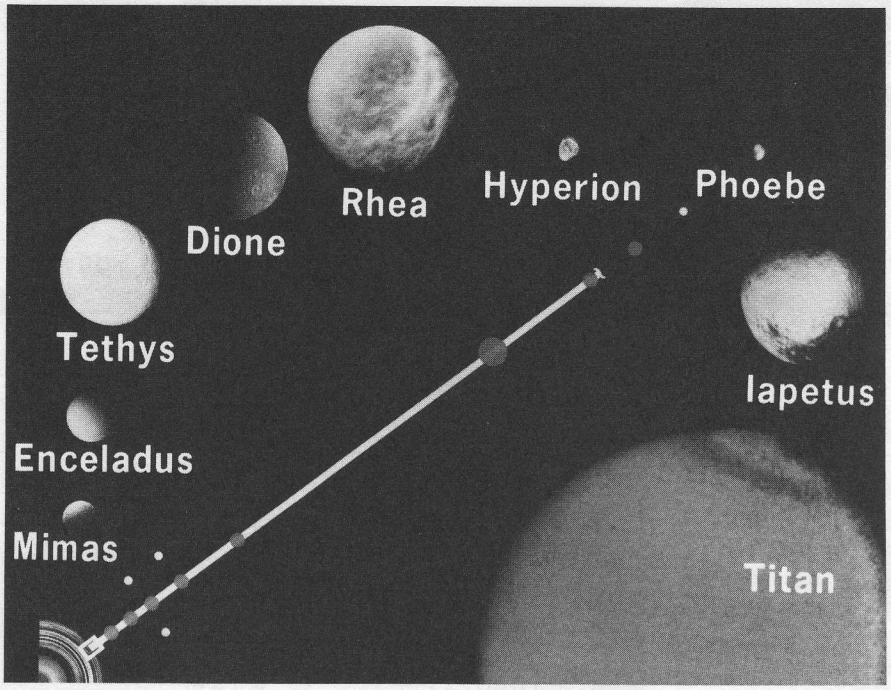
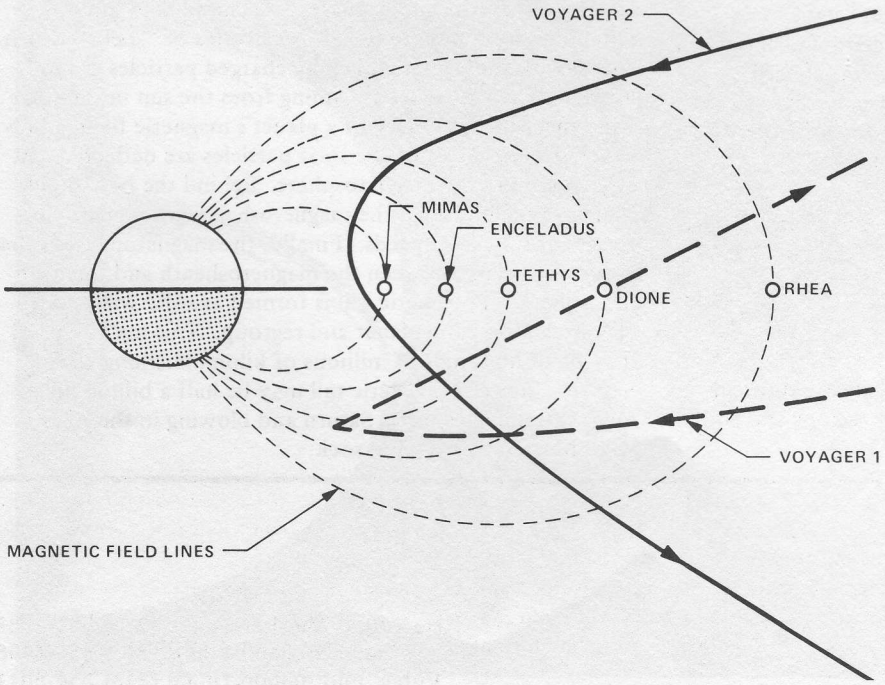


Some of the Voyagers' best resolution images of Saturn's larger satellites are shown in this composite. The diagonal line references the satellites' distances from Saturn to scale. The box drawn over the rings indicates the area where most of the small satellites are found. Moving outward from the planet, the satellites are Mimas, Enceladus, Tethys with its two companions, Dione with its small orbit-sharer, Rhea, immense Titan, and Hyperion. The line break indicates a break in the scale since Iapetus and Phoebe orbit at great distances beyond the other satellites. The satellites fall into three general classes: the tiny "rocks", the medium-sized icy satellites, and planet-sized Titan. The dark polar band in Titan's atmosphere can be seen in this image.

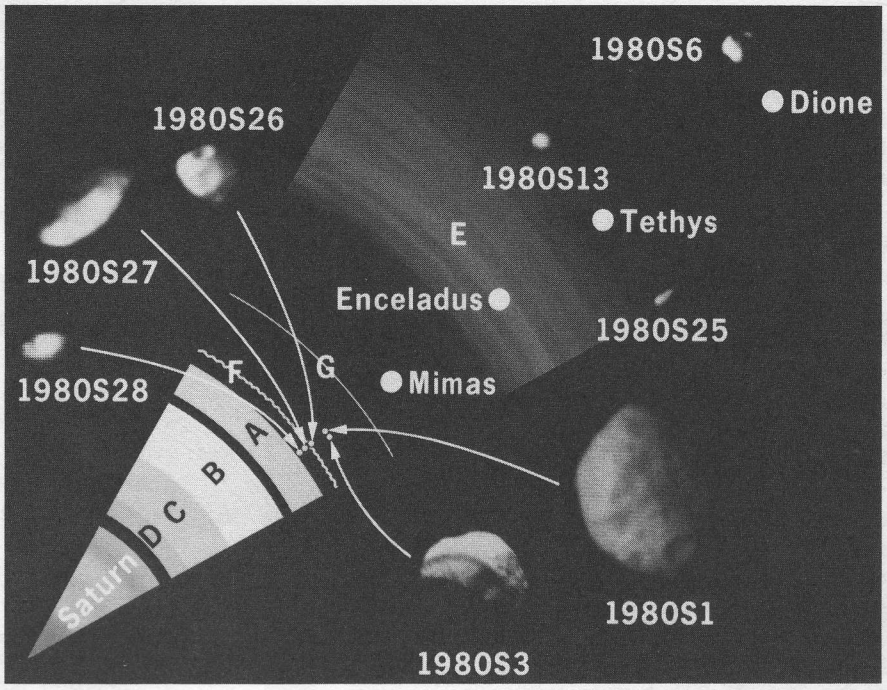
The orbit of Titan appears to be completely within Saturn's magnetosphere about 80 percent of the time, as the magnetosphere boundary ebbs and flows with the changing solar pressure. The interaction of the satellites with the magnetosphere is a prime area of study for the Voyagers. As the inner satellites orbit the planet, they clear a path through the charged particles in the magnetosphere and leave a wake much like a motor boat leaves. Like the motor boat's wake, the disturbance gradually quiets and returns to normal until the satellite comes around again. In addition, the satellites absorb charged particles as they spiral down Saturn's magnetic field lines. Measurements taken below the plane of the satellites show fewer protons in the satellites' "shadows". At Mimas, measurements of both the wake and the shadow indicate that another small body may be sharing the orbit.

Saturn is surrounded by two donut-shaped clouds of gases. The inner cloud (or torus) is comprised of ionized oxygen which is believed to originate from the icy satellites Tethys and Dione. The mass of the oxygen torus is one-fiftieth that of the Io sulfur torus at Jupiter. Io's volcanoes supply material to the torus at the rate of one ton per second; Tethys and Dione supply material at the rate of about one pound per second.

The oxygen torus extends to about halfway between the orbits of Dione and Rhea, where it meets the inner edge of a neutral hydrogen torus. This larger torus extends beyond the orbit of Titan to the magnetosheath. Its source may be Titan's atmosphere.



The trajectories of Voyagers 1 and 2 are shown in relation to each other and to the inner Saturn system in this meridian plane plot. Voyager 2 passed about 5200 km closer to the planet. Dipolar magnetic field lines passing near the satellites are shown as dashed lines. These field lines correspond to the magnetic L-shells, associated with the satellites.



Eight of Saturn's small satellites are shown in this composite of Voyager 1 and 2 images. 1980S28, 1980S27, and 1980S26 are sometimes called the "shepherding" satellites as they appear to influence the F-Ring and the outer edge of the A-Ring. Just 50 kilometers separates the orbits of 1980S3 and 1980S1, the co-orbitals. 1980S13 and 1980S25, the Tethys trojans, occupy Lagrangian points near the satellite, as does 1980S6, the Dione trojan.

Satellites

Winging its way into the Saturn system, Voyager 2 was geared to find small moons within the rings and near the larger satellites. Ground-based searches for such small moons had been fruitless, and so has been Voyager 2's photographic search. The cosmic ray instrument, however, may have detected a small moon sharing an orbit with Mimas, based on changes in the electron density in the satellite's wake.

Saturn's seventeen satellites fall into three main classes: giant Titan, seven intermediate-sized icy satellites, and eight small moonlets. Phoebe, Saturn's outermost satellite, may represent a fourth class: captured asteroids.

Voyager 2 flew closer to Enceladus, Tethys, Hyperion, Iapetus and Phoebe than did Voyager 1 last November, but was also able to study Mimas, Dione, Rhea, and Titan from greater distances.

Titan is shrouded by a thick atmosphere composed of about 82 percent nitrogen, topped by a multilayer haze. Neither Voyager 1 nor Voyager 2 was able to see below the clouds with their imaging cameras, but did obtain information on its size, temperature, and composition. It is slightly smaller than Jupiter's moon Ganymede, the largest moon in the solar system (both are larger than the planets Mercury and Pluto). Titan's surface temperature is about -290°F. About six percent of the atmosphere is methane, which may act like water does on Earth – as vapor, liquid, and ice. The remaining 12 percent of the atmosphere may be argon, a colorless gas undetectable with spectroscopy, and traces of compounds of carbon, hydrogen, and nitrogen (including ethane, ethylene, and acetylene). Titan's atmosphere in the northern hemisphere appears darker than its southern hemisphere. A dark polar hood seen by Voyager 1 has changed and Voyager 2 photographed a dark polar collar.

Seven of Saturn's satellites are intermediate in size, as planetary satellites go, ranging in size from about 290 to 1530 kilometers (180 to 950 miles) in diameter. (Jupiter's satellites are either very much larger or very much smaller than these.)

Enceladus, seen at higher resolution (2 km) by Voyager 2 than by Voyager 1 shows evidence of a great deal of geological activity in its past. Its surface areas range from heavily cratered to smooth, indicating that some regions have been resurfaced. One possibility is volcanic activity, although on Enceladus these would be water volcanoes since the satellite is comprised mostly of ice. The volcanic theory is supported by the fact that the tenuous E-Ring, which spans more than 90,000 kilometers (60,000 miles) across space, is brightest near the orbit of Enceladus, suggesting that Enceladus may be a source of E-Ring particles. The appearance of the surface of Enceladus also seems to indicate crustal heating in the geologically recent past, possibly from tidal heating caused by interaction with Dione. It is such tidal heating that causes volcanoes on Io, Jupiter's sulfur-spewing satellite. It should be noted, however, that the orbit of Enceladus would have to have been much more elliptical in its past to provide sufficient tidal heating.

Tethys is grooved around nearly three-quarters of its circumference by a chasm several kilometers deep, one hundred kilometers wide, and 2000 kilometers long. The canyon, comparable in dimension to Mar's great Valles Marineris, may have resulted from the expansion of ice when Tethys cooled after its formation. Most of Tethys' surface is heavily cratered, indicating there has been no resurfacing. One enormous crater is larger in diameter than the satellite Mimas.

Hyperion is highly irregular in shape – a disk-shaped object about 400 x 250 x 200 kilometers. Voyager 2's pictures, with a resolution of 10 kilometers, showed Hyperion to be battered and scarred with craters.

A great debate has arisen among planetary scientists concerning the nature of Iapetus. It has long been known that it has a dark side facing forward in its orbit around Saturn and a bright side facing backward. The dark hemisphere is as black as asphalt – one of the darkest surfaces in the solar system. Since there are no brighter areas on this region, such as might result from meteorites punching

through the black material to the icy crust and spraying out lighter-colored debris, the black coating must either be thick or constantly resupplied. Some scientists believe the black material comes from Iapetus' interior, while others believe it is external in origin – perhaps a coating of dust from Phoebe.

Phoebe, the last of Saturn's satellites to be observed by Voyager 2, is probably a captured asteroid.

Eight tiny moonlets also orbit Saturn. They appear to interact with the larger moons and to "control" the rings to some degree. 1980S28 orbits just outside the outer edge of the A-Ring. 1980S27 and 1980S26, the so-called "shepherding" satellites, flank the F-Ring, apparently herding it between them. 1980S3 and 1980S1, the "co-orbitals", share an orbit between the F- and G-Rings, playing a kind of cosmic leapfrog as they switch orbits in a four-year cycle. 1980S13 and 1980S25 share an orbit with Tethys, occupying mathematical points of stability (Lagrangian points) 60° ahead and behind the larger satellite. Similarly, 1980S6 orbits 60° ahead of Dione. Ground-based searches for other tiny moons at Lagrangian points of the other satellites have located none. However, a tiny moon is suspected to share the orbit of Mimas, based on data from the cosmic ray instrument.

For more information about the Voyager mission to Jupiter and Saturn, refer to the open literature, for both scientific and popular audiences. The following sets of articles represent official summaries of the mission and the results:

Space Science Reviews, Vol. 21, No. 2, November 1977.

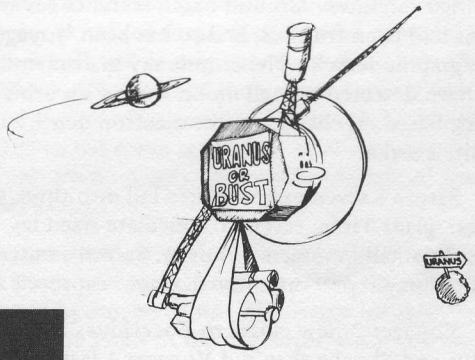
Space Science Reviews, Vol. 21, No. 3, December 1977.

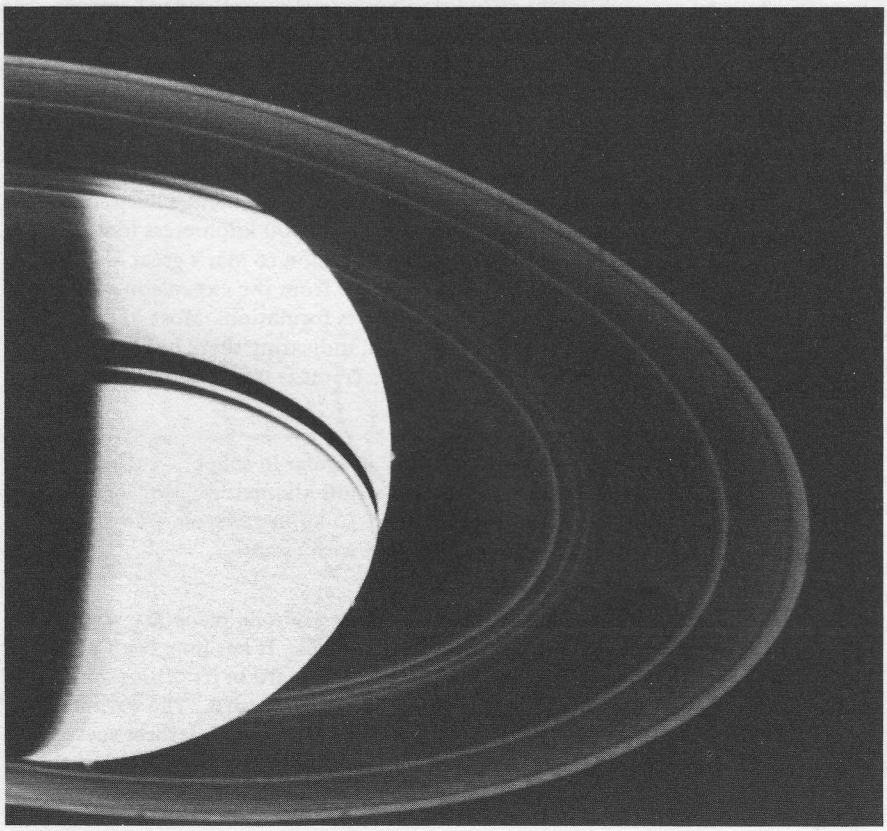
Science, Vol. 204, June 1, 1979, pp. 945-1008, 913-921 (Voyager 1 Jupiter results).

Science, Vol. 206, November 23, 1979, pp. 925-996 (Voyager 2 Jupiter results).

Science, Vol. 212, April 10, 1981, pp. 159-243 (Voyager 1 Saturn results).

Science (planned publication date January 1982) (Voyager 2 Saturn results).





This was one of the first pictures obtained once Voyager 2 resumed returning images on August 28 after its scan platform was commanded to point to Saturn again. Problems with the platform, on which Voyager's cameras and three other instruments are mounted, had prevented the return of images for several days after closest approach to the planet on August 25. Outbound observations were of the southern hemisphere and the unlit side of the rings. Voyager 2 crossed the ring plane only once, dipping below it about 1200 kilometers (750 miles) outside the G-Ring shortly after closest approach to the planet. This view shows some detail and differences in the complex ring system. The "reddening" of the B-Ring on the unlit side also was seen in Voyager 1 images. The shadow of the rings falls across the planet's equator in this view. 3.4 million kilometers (2.1 million miles)

Voyager Bulletin

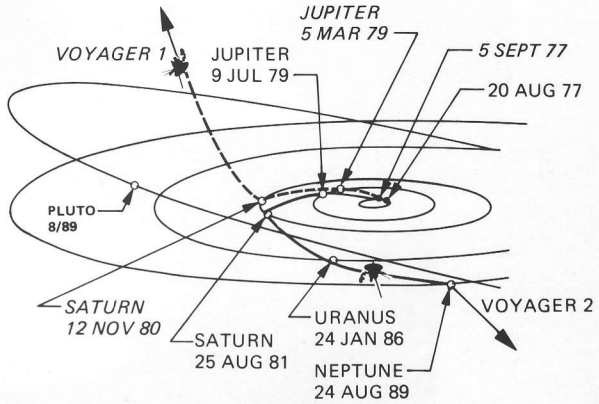
MISSION STATUS REPORT NO. 68 APRIL 10, 1985

Two interplanetary explorers, Voyagers 1 and 2, continue to ply the solar system nearly eight and a half years after beginning their journeys to the outer planets.

Voyager 1, launched September 5, 1977, made its closest approach to Jupiter on March 5, 1979, and to Saturn on November 12, 1980. Voyager 1 is now escaping the solar system with a speed of about three and a quarter billion miles per year, 35 degrees above the ecliptic, the plane in which the planets orbit the Sun.

Voyager 2, launched on August 20, 1977, was placed on a slightly longer flight path that would allow it to become the first spacecraft from Earth to observe the planets Uranus and Neptune. It flew by the giant planet Jupiter on July 9, 1979 and then past the ringed planet Saturn on August 25, 1981. With the successful completion of the Jupiter and Saturn primary missions, the Voyager project received approval and funding to continue to track and operate both spacecraft. Voyager 2 will make its closest approach to Uranus on January 24, 1986, passing within 110,000 kilometers (68,000 miles) of the planet's center.

Although Voyager 1 will not encounter any more planets, it continues to measure fields and particles; to conduct astronomical observations in the ultraviolet; and, along with Pioneers 10 and 11, to search for the outer boundary of the solar wind. The Pioneer spacecraft are leaving the vicinity of the Sun in the plane of the ecliptic, but in opposite directions. How will we know when the spacecraft have entered interstellar space? First, the solar system has been defined in several ways. The simplest definition includes only the regions of the nine planets and their satellites. The most far-reaching includes everything that is gravitationally bound to the Sun, a region that extends out to the Oort cloud of comets at about 40,000 AU*. By the first definition, Pioneer 10 has exited the solar system, since it has passed beyond the orbit of Pluto. None of the spacecraft are anywhere near the Oort cloud. There is an intermediate definition of the solar system, called the heliosphere. This is the region populated by the solar wind, the charged particles flowing from the Sun. The heliosphere is thought to be shaped like a wind sock, with a bulbous leading edge in the direction the solar system moves through space and a trailing edge flowing in the opposite direction. Several indicators will signal the passage of the



spacecraft out of the heliosphere. Instruments onboard the spacecraft are sensing the Sun's magnetic field and the solar wind. Scientists expect that when the spacecraft leave the Sun's magnetic field, the exit will be signalled by a change in the speed, direction, and character of the particles the spacecraft sense. In addition, the spacecraft are picking up radio pulses believed to come from the heliopause, the farthest reach of the heliosphere. The signals could come from charged particles in interstellar space pushed aside by the heliopause. If this proves true, Voyager 1 could cross into interstellar space as soon as 1991.

When Voyagers 1 and 2 were launched in late summer of 1977, the NASA-approved Voyager mission extended only slightly beyond Voyager 2's encounter with Saturn in August 1981. As both spacecraft were operating well after Voyager 1's successful Saturn mission, NASA and Congress approved the current Voyager Uranus/Interstellar Mission, which extends through March 1986. Voyager 2's Neptune mission, along with the continued operation of Voyager 1 through this period, is included in NASA's budget plan as a new start in fiscal year 1986, and no problems are anticipated in receiving funds to fly the Neptune mission.

Extended observations of Uranus will begin on November 4, 1985 and continue through February 25, 1986. Future issues of the Voyager Bulletin will focus on preparations for the encounter, including the health of the spacecraft, science objectives for the encounter, and capabilities for sending and receiving data over large distances.

An astronomical unit is the Earth's mean distance from the Sun, 150 million kilometers (93 million miles).

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JPL 410-15-68

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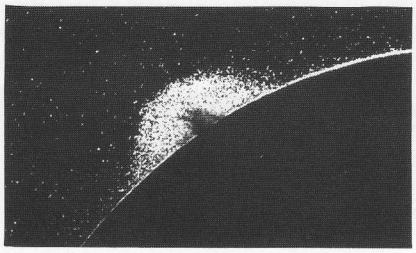

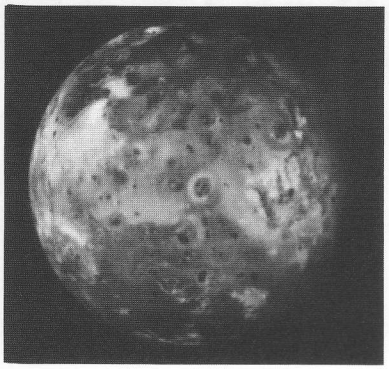

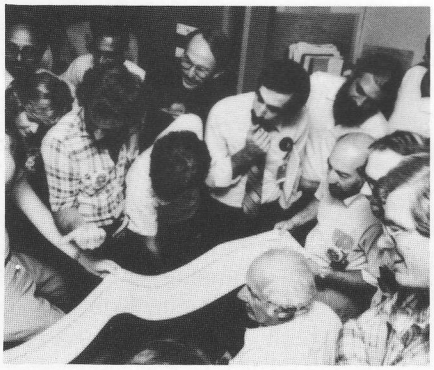

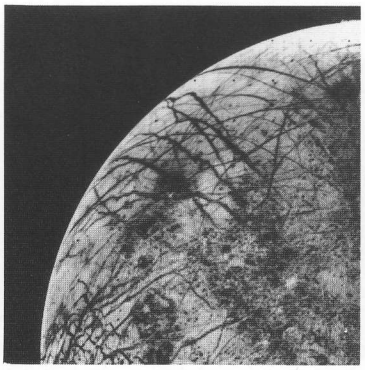

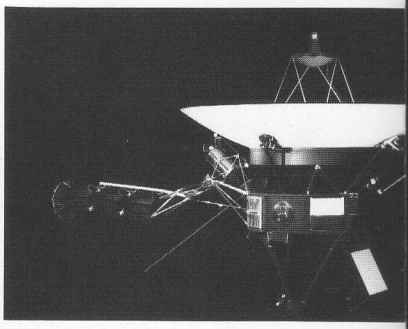

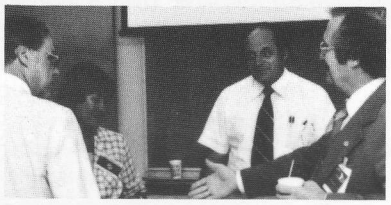

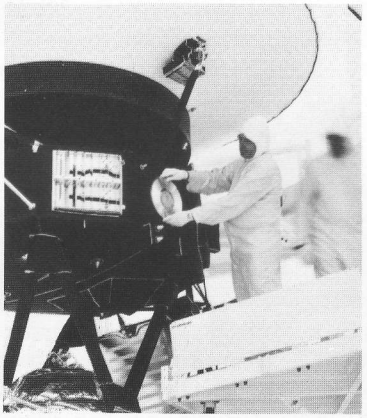

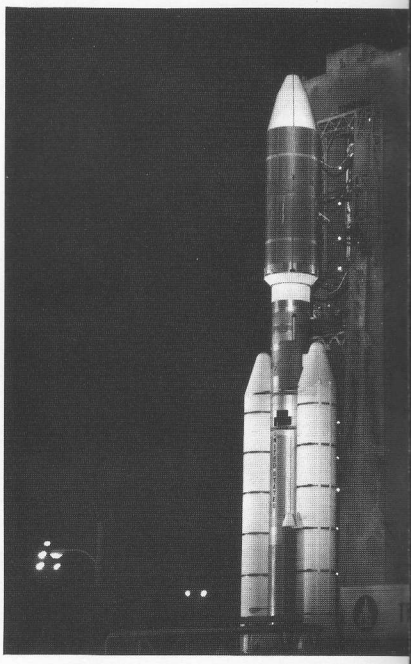

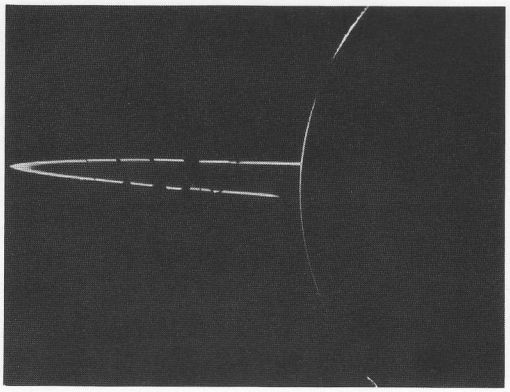

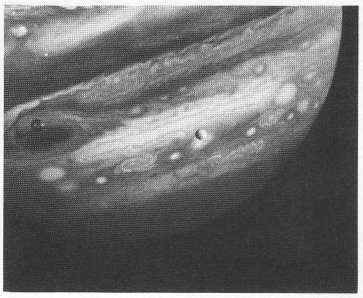

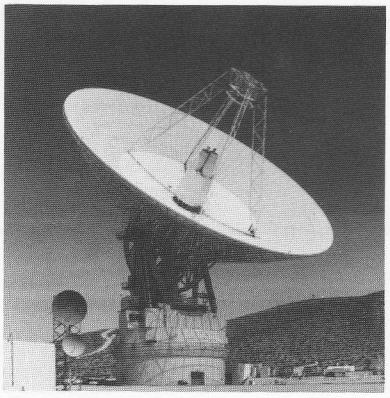

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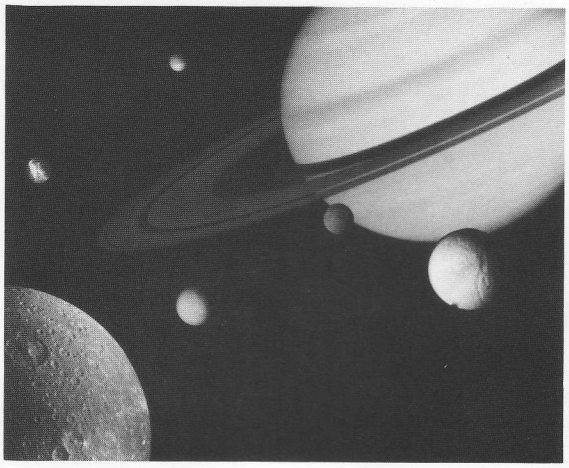

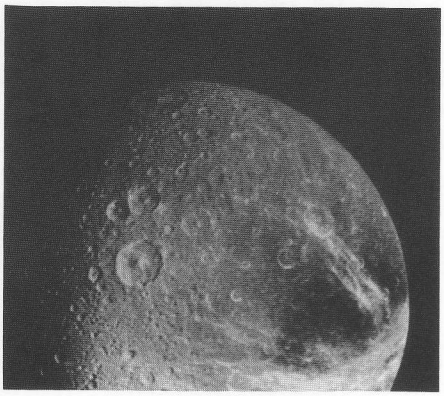

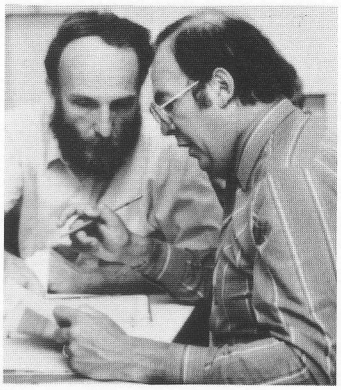

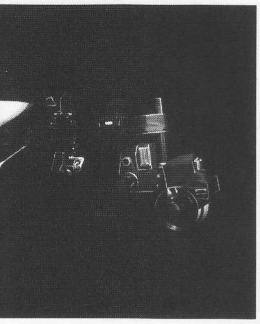

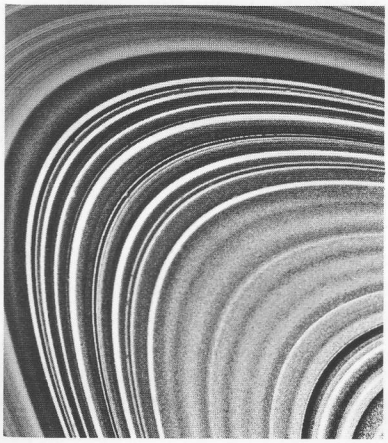

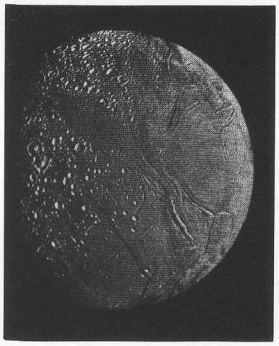

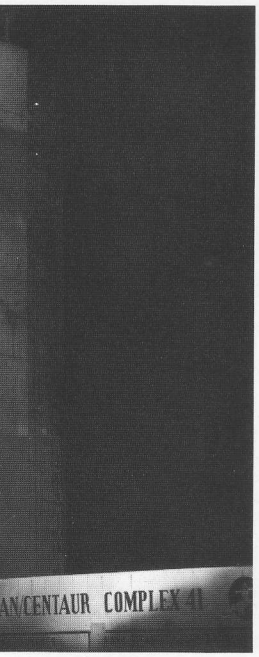
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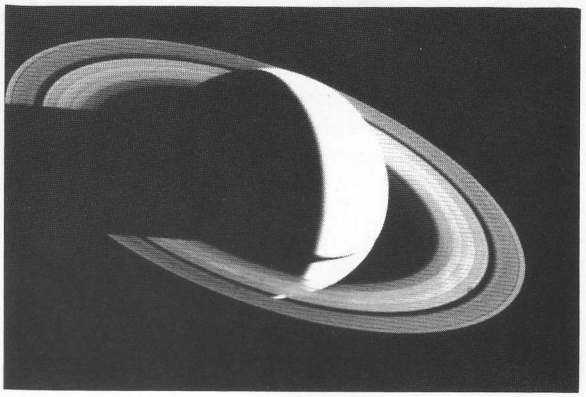

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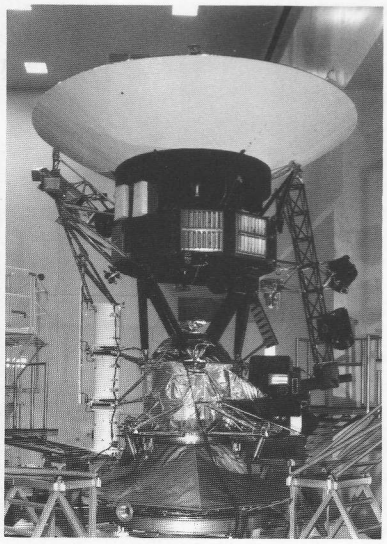
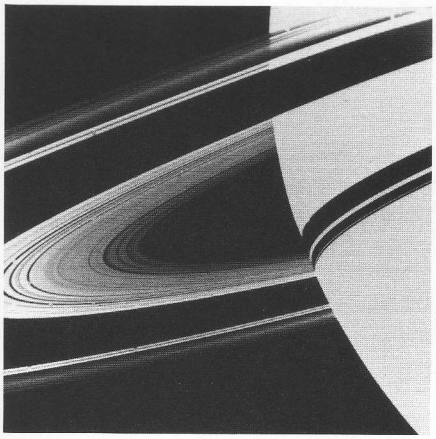




Uranus

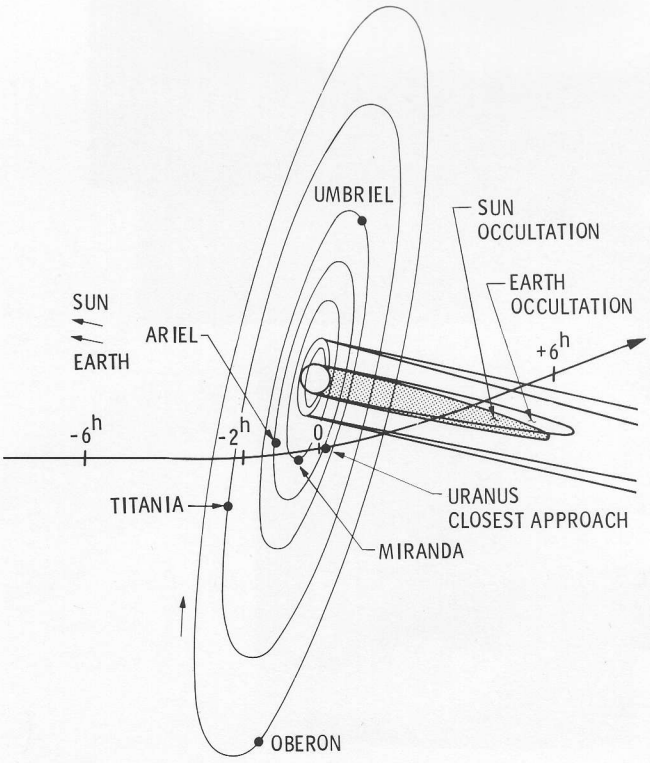
Relatively little is known about Uranus due to its great distance from the Earth. Unknown to the ancients, it was discovered in 1781 by Sir William Herschel, and its very dark ring system was not discovered until 1977. Voyager 2 will truly be a pathfinder as it will be the first spacecraft to observe Uranus from close range.

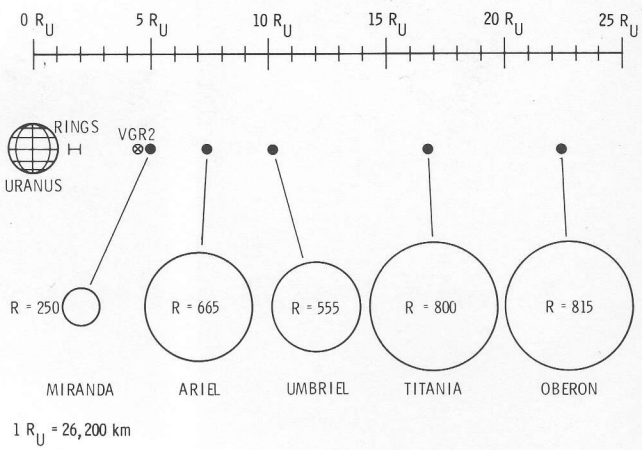
Uranus is the seventh planet from the Sun, and is almost a twin in size to Neptune, the eighth planet. [Both rank in size behind Jupiter (the largest planet) and Saturn.] It orbits the Sun at about 19 astronomical units* and makes one revolution every 84 years.

Uranus, its rings, and satellite orbits present a bull's-eye target to Voyager 2: the planet is tilted on its rotational axis and the illuminated pole presently points almost directly to the Sun. This unique orientation means that significant events of the Uranus encounter, such as satellite encounters and ring plane crossing, will be compressed into about 5-1/2 hours, as compared to 35 hours for the approaches to Jupiter's Galilean satellites and 13 days for the satellites out to Phoebe's orbit at Saturn.

Voyager 2 will try to pin down the radius of Uranus, now thought to be about 26,200 kilometers (16,300 miles), and its rotation rate, which is believed to be about 16 hours. Current theories also propose a composition that is about 24 percent rocky core material, 65 percent icy mantle, and 11 percent hydrogen-and-helium-rich atmosphere by mass. The planet's density is about 1.19 grams per cubic centimeter.

There are five known satellites of Uranus: ranging outward from the planet, they are Miranda, Ariel, Umbriel, Titania, and Oberon. They are slightly smaller than Saturn's large icy satellites Dione, Iapetus, and Rhea, with diameters ranging from 500 to 1630 kilometers (300 to 1000 miles). Although their surfaces are fairly dark, they are probably of water ice. Titania and Oberon appear to be denser than





Umbriel and Ariel, while the density of Miranda is too poorly determined to make comparisons. There is some speculation that whatever catastrophic event caused Uranus to tip on its side may have also deeply affected the satellites, and they may be the highlight of the Uranus encounter.

Since the Uranian rings were discovered by astronomers in 1977, a total of nine sharp-edged, narrow ringlets has been observed; some of them are eccentric (that is, non-circular) and some are inclined to Uranus's equator. Ranging outward from the planet, they are designated 6, 5, 4, alpha, beta, eta, gamma, delta, and epsilon. Their widths range from half a kilometer to nearly a hundred kilometers and they spread from about 41,880 to about 51,190 kilometers from Uranus. The eccentricities may be caused by the pull of small satellites embedded in the rings or orbiting nearby. One of Voyager 2's prime activities will be to scan the rings for such small bodies. Recently, two members of the Voyager Imaging Team, Brad Smith and Rich Terrile, photographed the rings in the infrared using an Earth-based telescope with a charge-coupled device (CCD).

Although it has not been established that Uranus has a magnetosphere, it is reasonable to expect to find one there since the planet is similar to Jupiter and Saturn in many other respects. The International Ultraviolet Explorer (IUE) spacecraft has observed hydrogen emissions at Uranus that have been attributed to aurora, phenomena that are caused at other planets (including Earth) by charged particles spiralling into the planet's atmosphere along magnetic field lines. Voyager 2 will encounter the Uranian magnetosphere nearly pole-on, presenting the opportunity for some interesting magnetospheric studies at high latitudes.

Voyager 2 has been observing Uranus for well over a year now, but only recently have the images taken for optical navigation and photometry purposes begun to exceed the resolution available from the best Earth-based telescopes. They show a fuzzy grey disk a few pixels across; the rings are not visible. The images are used mainly for targeting and determination of reflected light as a function of viewing angle. As Voyager 2 homes in and the images become sharper, scientists will try to identify and track cloud features in efforts to determine the rotation period of Uranus' atmosphere. If Uranus is like Jupiter and Saturn, the planetary radio astronomy (PRA) experiment should be able to measure the interior rotation rate of the planet. A comparison of these two sets of measurements will let scientists deduce atmospheric wind speeds.

Voyager Bulletin

MISSION STATUS REPORT NO. 69 JUNE 20, 1985

Scan Platform Is Healthy

Voyager 2 is expected to return nearly 6,000 images of Uranus and its satellites over a 4-month period in late 1985 and early 1986, but there was a time when the ability of the spacecraft to complete its Uranus mission as planned was in grave doubt due to problems with a scan platform actuator. The actuator controls movement of the steerable platform on which the remote sensing instruments are mounted.

The fact that the scan platform will be used at Uranus is due to an intensive program of detective work to determine the cause of the failure, to devise ways to use the platform in the future, and to monitor its health.

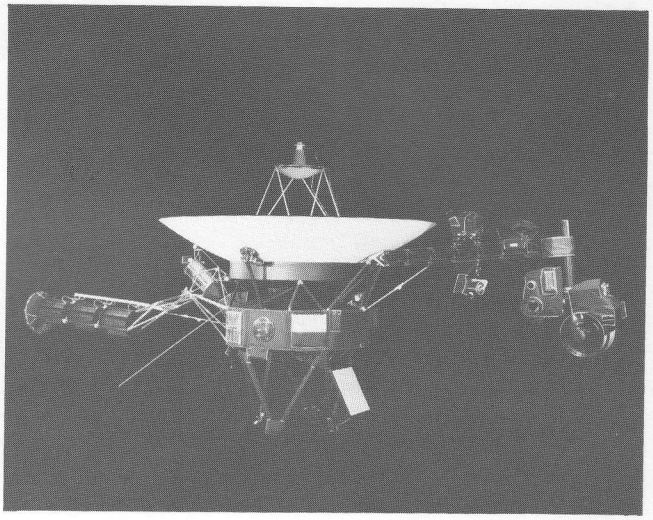
The Onset

On August 25, 1981, Voyager 2 passed within 101,000 kilometers (63,000 miles) of Saturn's cloudtops, the bulk of its Saturn observations completed. Still to come were observations of the planet's dark side and southern hemisphere, the underside of the rings, and several satellites. Right on schedule, radio communications ceased as the spacecraft entered the planet's shadow and the planet's bulk blocked radio signals. During this hour-and-a-half Earth occultation period, the spacecraft was programmed to continue its observations, recording the data for later transmission to Earth. As the spacecraft emerged from behind the planet shortly after midnight on August 26*, communications resumed and it was immediately apparent that the scan platform had trouble. The images showed deep space rather than Saturn's rings. Engineering telemetry showed that the platform had failed to complete a high rate (one degree per second) slew in azimuth (on Earth, this would be the horizontal direction).

Fault protection routines onboard the spacecraft detected the failure and automatically commanded the platform to slew to a "safe" position to protect the delicate optics of the instruments from direct sunlight, but this slew also stopped short. The platform appeared to have seized in the azimuth axis.

At first, it was thought that the problem was similar to that experienced on Voyager 1 in early 1978. In that case, the probable cause of platform sticking was a small piece of debris (possibly plastic) in the gear train. The platform was freed by running the gears back and forth until the debris broke up or was crushed and normal motion was restored.

Times given are Earth-receipt of signal, Pacific Daylight Time. At that time, signals from the spacecraft required about 1 hour 26 minutes to reach Earth, travelling at the speed of light.



Voyager's scan platform (far right) carries the wide- and narrow-angle cameras, ultraviolet spectrometer, infrared interferometer/spectrometer, and photopolarimeter.

Several days after the Saturn flyby, commands were sent to Voyager 2 to perform several small low-rate slews necessary to obtain some critical science observations. These were successful. Normal slewing resumed, and the platform was used sparingly and with no further problems for the remainder of the Saturn encounter period. Two weeks after the failure first occurred, the platform stopped again during engineering tests designed to evaluate slewing behavior and actuator operation at all slew rates. The cause of the failure seemed different from that on Voyager 1.

All slewing was restricted on Voyager 2 while an intensive program of testing was conducted on the ground to determine the cause of the failure, determine the best operating conditions, and estimate the remaining lifetime of a failed actuator once it was restored to operation. In view of the actuator's recovery immediately following the failure, there was some hope that the platform could be used for the Uranus encounter.

Ground Tests

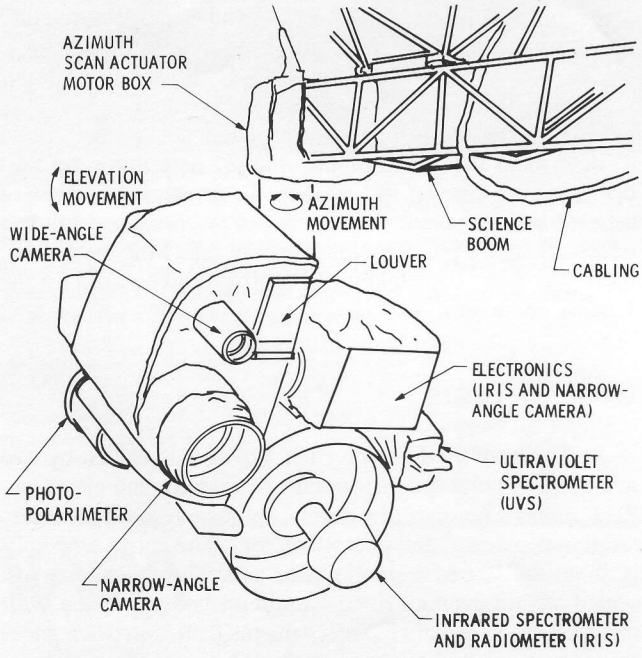
The scan platform on each Voyager is driven by two actuators to point the instruments in azimuth and elevation. Each actuator consists of a permanent magnet stepper motor, reduction gearing, and potentiometers. The entire assembly is about the size of a small coffee can. These elements are sealed within a pressurized aluminum housing filled with nitrogen gas to protect the mechanisms from corrosive gases prior to launch and to preserve the lubricant. The actuators can point the platform with an overall accuracy better than

0.14 degree, travelling in steps of 0.028 degree at one of four rates: high (1 degree per second), medium (1/3 degree per second), low (1/12 degree per second) and very low (1/192 degree per second). The azimuth actuator can travel nearly 360 degrees, while the elevation actuator can travel through about 210 degrees.

The ground tests focused on three areas: using the prototype actuator to determine the cause of the failure, trying to recover motion in the flight spare actuator once it was purposely failed, and operating vital mechanical parts under a variety of conditions.

The first tests, conducted by mechanical engineer Carl Marchetto, tried to duplicate the failure, operating a prototype actuator in simulated flight conditions. The prototype failed after 348 revolutions—four less than the actuator on the spacecraft. Both devices had failed much sooner than their designers expected. Upon disassembling and examining the prototype actuator, it was found that the first gear cluster had seized on its supporting shaft, apparently due to a lubrication failure which led to galling of the shaft. Material removed during the galling process was redistributed, eventually reducing clearances between moving parts and ultimately causing the gear cluster to seize.

With a theory of the primary cause of the failure set forth, the next step was to test the flight spare, a unit constructed at the same time as the four actuators on the two spacecraft. This unit was also operated until it failed, but rather than disassemble it (since it was the nearest thing to a flight actuator available, it wouldn't be wise to destroy it), engineers tried various ways to recover (restart) it. The most effective method proved to be varying the actuator's temperature from +10°C to −35°C (50°F to −31°F) [normal operating temperature on the spacecraft is −7°C (19°F)]. The temperature can be controlled by turning on instruments, the actuator heater, and the motor coils in different combinations. The temperature changes cause the actuator's parts to expand at different rates, crushing any material that might accumulate from the galling process.



The scan platform can be rotated about two axes to provide precision pointing for its four remote sensing science instruments.

The flight spare was intentionally failed at various rates and recovered many times under a variety of conditions. Statistics were gathered regarding its probability of failure.

"We found out fairly soon that slew rates were a big factor in the failure. The flight spare never failed at low rate, almost always at high rate, and sometimes at medium rate," said Bill McLaughlin, manager of Voyager's Flight Engineering Office.

The third series of ground tests investigated operating conditions that might affect the actuator's lifetime. Numerous "boxes" of bearing/gear assemblies were built by JPL's specialty machine shop and lubricated for these tests. (A very few were tested without lubrication and failed immediately.) The boxes were run at various rates until they failed, then motion was restored by varying the temperature. After failure and recovery, groups of boxes were then subjected to different operating conditions. Their operating lifetimes after failure and recovery were statistically compared using a test developed by Donna Wolff of the Flight Engineering Office. In this way, optimal operating conditions were developed for future use of the flight actuator.

"Experts also chemically analyzed the interaction between the lubricant and the shaft materials, and used an electron microscope to analyze the bearing surfaces," explained Mike Socha, a mechanical engineer in JPL's Guidance and Control Section.

This phase of testing provided the information necessary to develop the failure model and to recommend how to use the actuator. The tests showed that actuator life is significantly lengthened by low rate operation and an additional temperature cycle.

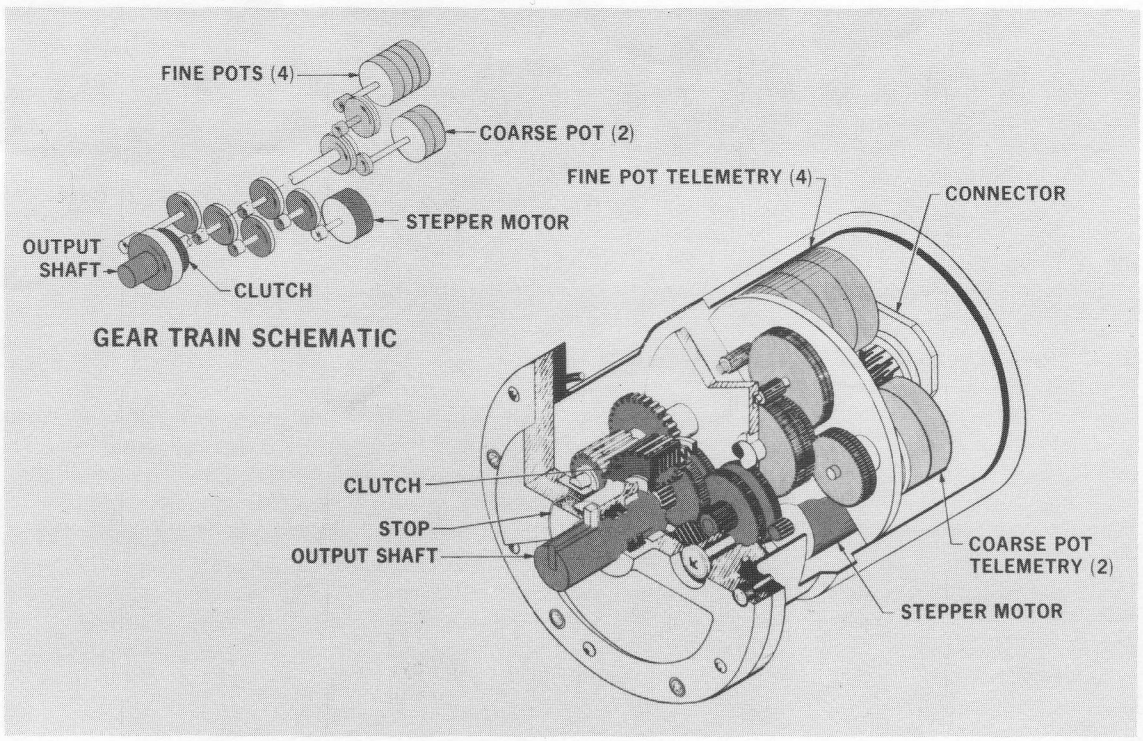
"Through this series of tests we gained a lot of information on how to keep an actuator going and what to do should the flight actuator seize again," said McLaughlin.

Health Checks

"There was a desperate need for a way to assess the health of the in-flight actuators," explained Howard Marderness, chief of Voyager's Spacecraft Team. "In late 1982, we began to develop ways to evaluate the torque margin of the in-flight actuators. One possibility involved varying the power-on pulse width to the drive stepper motor."

Reducing the pulse width reduces the torque applied by the motor to the gear train. If the pulse width is reduced enough, even a perfectly healthy actuator will fail to slew properly due to frictional losses in the system. The normal pulse width applied is 120 ms when slewing at the low rate.

"At first there appeared to be no way of varying the pulse width in the required range," said Marderness. After about four months of study, however, Gene Hanover and Jitendra Mehta of the guidance and control area conceived a means of doing this. Design and ground testing of the torque margin test patch was completed in mid-1983 and was first tested on the Voyager 1 actuators in August 1983. This was followed by testing of the Voyager 2 actuators in



The actuator problem is attributed to a lack of full lubrication in the bearing areas. Lubrication appears to have migrated back, healing the problem.

September 1983. The test results were very encouraging in that all four actuators onboard the two Voyager spacecraft slewed normally at pulse widths between 5 and 6 ms, which, as determined from ground tests, is about the same as for a new actuator. If erratic slewing behavior is noted at 8 ms, for example, it would be a good indication that the actuator was beginning to fail again. Currently, the actuators are monitored by periodic torque margin tests.

Critical Test Before Uranus

About 100 hours before closest approach to Uranus, a critical torque margin test will take place. Should the test show that the actuator's performance has degraded, a back-up encounter program will be sent to the spacecraft. This program will involve rolling the entire spacecraft to point the instruments.

The spacecraft roll axis and the scan platform's azimuth axis are nearly parallel, so roll motion of the entire spacecraft, together with motion of the scan platform in elevation, can be used to point the scan platform's instruments if necessary.*

The use of roll turns would allow basic observations at Uranus, but is not as desirable as pointing the platform. Scan platform pointing is generally more accurate, "settling time" is longer after a roll turn than after a platform slew, and commanded spacecraft turns require more computer instructions than does a slew command. There is also more risk involved in turning the spacecraft and more propellant is used.

Summary

No problems have returned on Voyager 2's azimuth actuator since operations resumed over two years ago. However, the actuator is being monitored periodically and used conservatively.

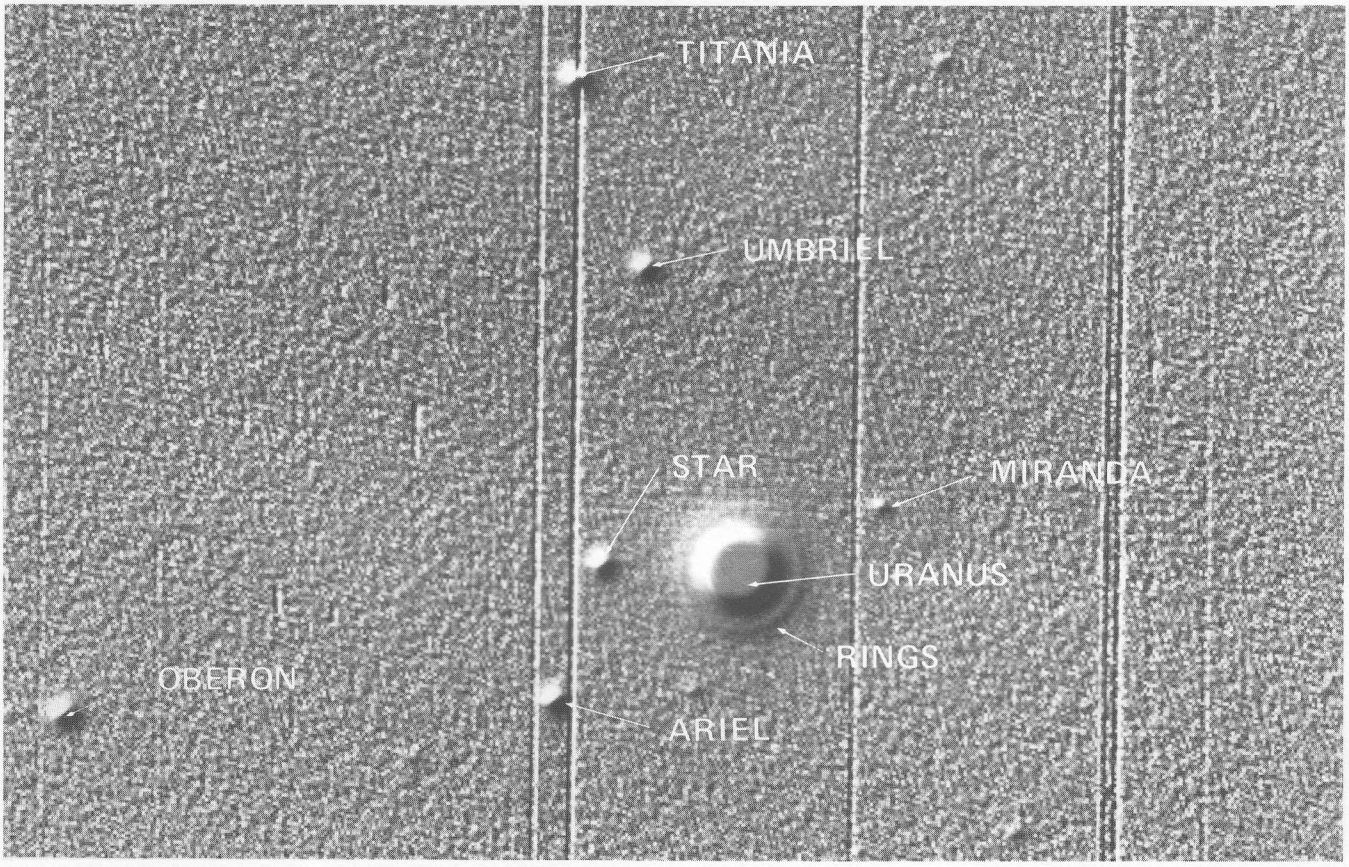
The final report on ground testing of the actuator attributes the failure to a lack of full lubrication of the bearing area between the gear and pin. Frictional heat builds up and causes the lubricant to become less viscous, leave the bearing area, and allow metal to metal contact. A complex chain of chemical reactions between the lubricants and materials also contributes to the manufacture of debris which then interferes with free motion.

It is speculated that the lubricant has migrated back to the bearing surfaces, thus healing the problem.

At Uranus, the platform slews will be primarily at low rate with a small number of medium rate slews for critical science observations. Eight roll turns have been substituted for large angle slews where possible. If there are any indications of problems just prior to the intensive encounter phase, a computer program will be sent to the spacecraft to substitute spacecraft roll turns for azimuth slews.

"Platform slewing is no longer a major topic for us," said McLaughlin. "We've developed plans to cope with it, and we've gone on to develop other capabilities and to train our staff to assure a successful Uranus encounter."

**If the spacecraft's elevation actuator were to seize, it would be difficult to substitute spacecraft turns for scan platform motion as both pitch and yaw turns point the high gain antenna away from Earth, thus breaking the communications link. Data would have to be recorded for later transmission to Earth.*



The first clear photograph of the rings of the planet Uranus is shown in this image taken from Earth. Computer processing creates a false three-dimensional texture to the image, but allows the dark rings to be seen near the much brighter planet. The collective ring system is shown, as the nine individual rings could not be resolved. The photo was taken by a new electronic camera employing a charge-coupled device (CCD) to record the original image. Bright vertical lines on the image are caused by minor defects in the detector. Dr. Richard J. Terrile of the Jet Propulsion Laboratory and Dr. Bradford A. Smith of the University of Arizona took the image at the Carnegie Institution's Las Campañas Observatory near La Serena, Chile.

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Space Administration

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Status Bulletin Editor (818) 354-4438
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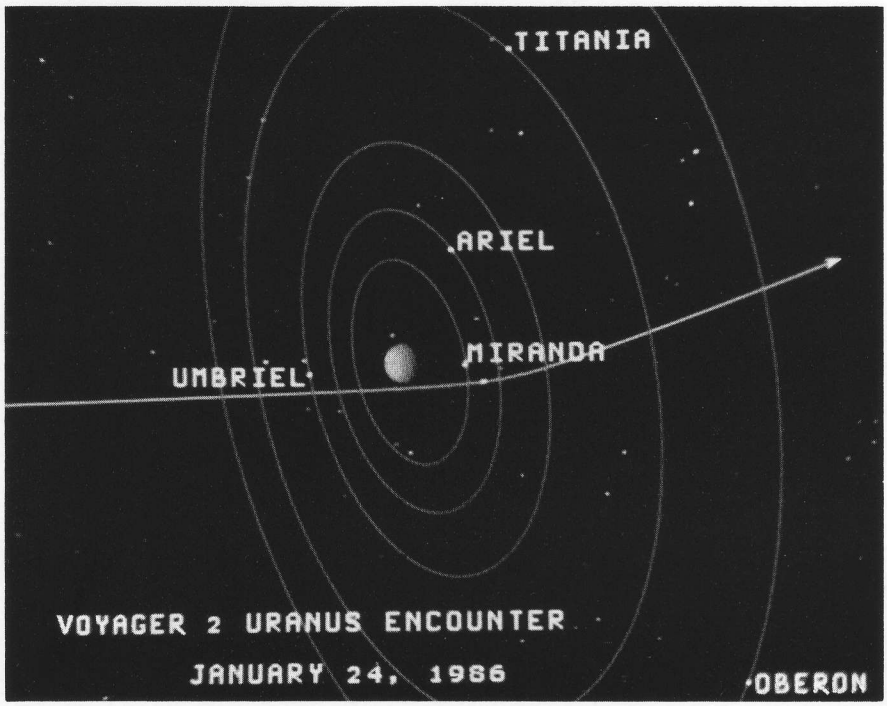
Voyager Bulletin

MISSION STATUS REPORT NO. 70 AUGUST 20, 1985



Voyager 2's path through the Uranian system is shown in this computer-generated view.

Uranus Science Objectives

Voyager 2 is truly a pathfinder at Uranus because so little is known about the seventh planet. In February 1984, Voyager scientists held a workshop to establish a scientific framework within which to plan the Voyager encounters with Uranus and Neptune. As a result of this workshop, a list of the 30 highest priority science objectives was compiled for Uranus, and Voyager 2 is now being programmed to perform experiments designed to meet these goals. Twenty-seven of these experiments occur in the 96-hour ''near-encounter'' period, most of them within 6 hours of Voyager's closest approach to Uranus.

Voyager will use its 10 scientific instruments and its radio to study the Uranian system. Four of these instruments are optical, and ride on the steerable scan platform. These include the wide and narrow angle cameras, the ultraviolet spectrometer, the infrared interferometer, and the photopolarimeter. Six other instruments measure energetic particles, radio emissions, and magnetic fields in space and near planets. These include magnetometers as well as instruments to measure plasma, plasma waves, planetary radio emissions, low-energy charged particles, and cosmic rays. Finally, the spacecraft's radio is used for very important scientific measurements as well as for communication with Earth.

The scientific observations can be categorized into several groups: planetary (atmospheric), satellites, rings, magnetospheres, and deep space. The observations are designed so that complementary data from several instruments contribute to knowledge in each of these groups.

So far, no structure has been seen in Voyager images of the Uranian atmosphere — no brightly colored bands or large storms as were obvious at Jupiter and Saturn. Scientists hope to observe and characterize the global circulation and meteorology of the upper, visible clouds, as well as the horizontal and vertical structure of these clouds and the nature of any colored material. Voyager will measure the hydrogen and helium abundances, in comparison to primitive solar abundances, and will also study the composition of the high atmosphere — be it hydrogen, methane, or acetylene.

The spin rates and shapes of the satellites will be studied, as well as the physical composition of these surfaces. The mass of Miranda will be determined by the amount of gravitational pull this small satellite exerts on the spacecraft during its very close (within 29,000 kilometers) pass. And, as was the case at both Jupiter and Saturn, additional, small satellites may be discovered.

In Voyager images to date, four of the five known satellites have been seen. Only Miranda has not been seen, probably because it is small, dark, and near the planet. The rings are so dark that many of our most important observations will be after closest approach, as the spacecraft swings behind the planet and observes the rings backlit by the Sun and also measures starlight passing through the rings. This will help determine the structure and density of the rings, possibly expose new rings, and detect diffuse material between the rings. As the spacecraft crosses the ring plane, it will search for tiny satellites embedded within the rings, and small satellites that ''shepherd'' ring material between them in a gravitational game of tag. Voyager will determine the size of the particles in the Uranian rings. At Saturn, Voyager determined that the size of the ring particles ranges from boulders to dust particles.

At this point, it is not known whether Uranus has a magnetosphere. Observations by the International Ultraviolet Explorer (IUE) spacecraft have detected what appear to be polar auroras on the planet, which implies that Uranus has a magnetic field. However, as late as July, Voyager's Planetary Radio Astronomy Experiment had detected no radio emissions from Uranus, perhaps weakening the case for the existence of a Uranian magnetic field. If Uranus does have a magnetic field, the fields and particles instruments will explore its structure and charged particle composition; locate the bow shock, magnetopause, trapped radiation, and magnetotail; determine the relationships between the magnetic field and the solar energetic particles; investigate the interaction of the planet or satellites with the plasma environment; study isotopes from hydrogen through sulfur; and measure the spectra and elemental composition of all cosmic ray nuclei from hydrogen through iron. Even if Uranus proves not to possess a magnetic field, these studies will provide important data on Uranus' interactions with the solar wind.

Two important scientific questions about Uranus are: what is its rotation rate? and does it have an internal heat source? Current direct measurements place the length of a Uranian day between 12 and 24 hours, but measurement of radio emissions from the planet will give the most precise figure. Measurements of wind speeds in the planet's atmosphere will give a less precise answer if there are no radio emissions to measure. Jupiter and Saturn both radiate about twice as much heat as they receive from the Sun, indicating that they have internal heat generators. By measuring the amount of sunlight absorbed by the planet as opposed to the amount of heat it radiates, Voyager will be able to determine if Uranus also has a hot interior. Observations on both the approach (sunlit hemisphere) and departure (shadowed hemisphere) from the planet are crucial to this measurement.

The Uranus encounter period has been divided into four phases: observatory, far encounter, near encounter, and post encounter. The divisions are based in part on the size of the images in the field of view of the narrow angle camera. The periods are:

Observatory: November 4, 1985 to January 10, 1986

Far Encounter: January 10–22, 1986

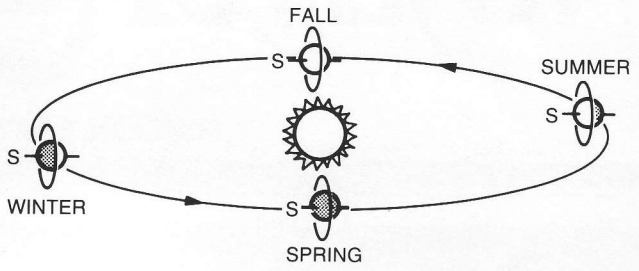
Near Encounter: January 22–26, 1986

(Closest approach to Uranus is January 24, 10 a.m. PST)

Post Encounter: January 26 – February 25, 1986

August 20, 1985 is the eighth anniversary of the launch of Voyager 2. On August 24, Voyager 2 will be four years from its 1989 encounter with Neptune.

Southern Summer



Seasons on Uranus last approximately 21 years, as different hemispheres face the Sun.

Uranus orbits the Sun once every 84 years, making for very long seasons on the planet. Spring, summer, autumn and winter — each lasts about 21 years at any particular spot on the planet.

To complicate matters even more, Uranus is tilted on its rotational axis so that its poles lie nearly in the plane of the ecliptic (the plane in which most of the planets and their satellites orbit around the Sun). In other words, Uranus lies on its side. So how does one establish a point of reference for north and south? The governing body for astronomical nomenclature, the International Astronomical Union (IAU), has established a convention that uses Earth as the reference: all poles above the ecliptic are north poles, all poles below the ecliptic are south poles. Since the Uranian pole currently illuminated by the Sun is tilted slightly (about 8°) below the plane of the ecliptic, it is designated the south pole by the IAU. It is this hemisphere that Voyager 2 is approaching.

A second nomenclature used with regard to poles involves the so-called "rotational pole". If one could imagine grasping the spin axis of a planet with the right hand in such a way that the fingers curled in the direction of the planet's rotation about its axis, then the rotational pole would, by definition, be the one in the direction of the thumb. For Earth and all of the planets except Uranus (whose rotation axis is tilted about 98° with respect to the north pole of the ecliptic) and Venus (which rotates clockwise rather than counterclockwise), the rotational pole corresponds to the north pole. No end of confusion and inconsistency has been generated by the lack of agreement in the cases of Uranus and Venus.

Editor ..... Anita Sohus

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JPL 410-15-70 8/85

Status Bulletin Editor (818) 354-4438
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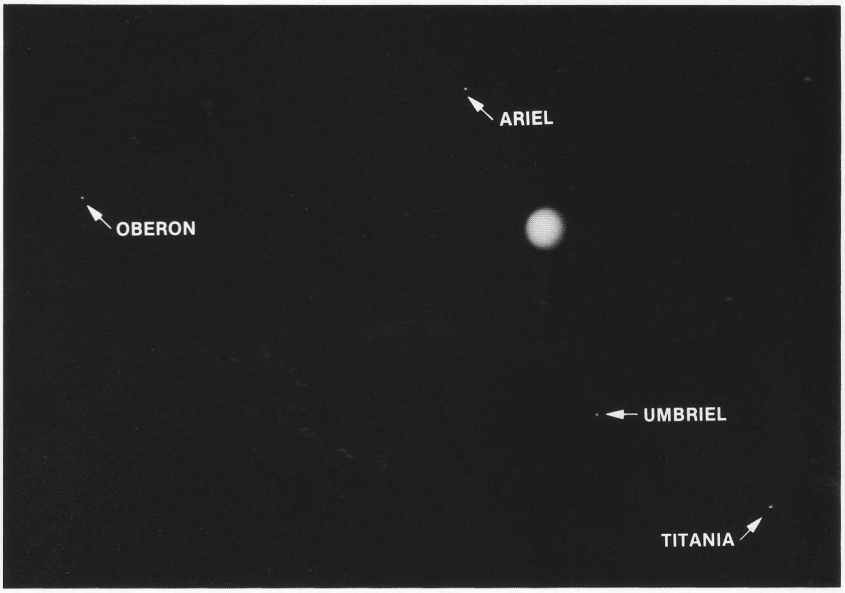
Voyager Bulletin

MISSION STATUS REPORT NO. 71 OCTOBER 28, 1985

Near Encounter Test

Last week, the Voyager flight team conducted a full dress rehearsal called near encounter test (NET) for Uranus, a final validation of the most complex portion of the near encounter activities to take place in late January. NET exercised the spacecraft, the flight team, and the Deep Space Network. The only thing missing was the Uranian system.

While there are many specific objectives for NET, they can be grouped into four general categories: 1) to verify the spacecraft's execution of the most complex part of the near encounter sequence, about ten hours worth; 2) to confirm radio science readiness—the ability of ground support to acquire and monitor the data; 3) to test the ability of the flight team to meet the timelines for generating and uplinking the late sequence updates; and 4) to simulate the frequency changes that affect the ability to command the spacecraft.



Uranus and four of its moons are seen in this Voyager 2 image taken July 15, 1985 at a distance of 247 million km. Satellite images from a long-exposure frame have been superimposed on the Uranus image and enhanced in brightness to make this composite.

"Some people say the purpose of near encounter test is to test the spacecraft, but I think it is more to test ground operations: are the people and equipment ready to handle what the spacecraft produces," explained Doug Griffith, manager of Voyager's flight operations office.

Near Encounter Load

"NET included all of the 'movable block'," explained Ellis Miner, assistant project scientist. "This movable block is a computer sequence containing the most complex part of the encounter period."

Included in this time frame will be closest approach to all five known Uranian satellites—Miranda, Ariel, Umbriel, Titania, and Oberon—in quick succession, as well as closest approach to the planet, crossing the ring plane, and Earth and Sun occultations (as the spacecraft passes behind the planet, radio communications with Earth and light from the Sun are temporarily blocked).

All of Voyager 2's instruments were operating and making observations during NET. The scan platform was slewed to point its instruments, but of course images were of deep space rather than Uranian objects. These images will be used to validate the pointing.

Tests of image motion compensation maneuvers were included in NET. At Uranus, where light levels are approximately 400 times dimmer than at Earth, camera apertures must be open longer to gather more light. Combined with the motion of both the spacecraft and the target body, this would result in lower resolution images. Merely slewing the scan platform to track the body (similar to panning the motion of a racer with your own handheld camera) would not be effective since, for one thing, the platform slews in steps rather than one smooth motion. The solution is to use the spacecraft's attitude control system in a new way. The spacecraft is normally stabilized by celestial references, but it can also be stabilized by internal gyros, using the attitude control thrusters to compensate for drift. To compensate for image motion, the spacecraft will be put under control of the gyros at a proper drift rate during the image exposure time. Using this technique, the resolution of Miranda images, for example, will be improved by a factor of 50.

Radio Science

Radio science experiments at Uranus require precise timing and coordination among many elements of the project and NASA's Deep Space Network (DSN).

The highest value science data will be returned to Earth while the spacecraft is "over" the Australian Deep Space Communications Complex, where one 64-meter antenna and two 34-meter antennas will be arrayed with the 64-meter Parkes Radio Observatory antenna (located about 320 kilometers to the northwest) to form one large aperture to capture the spacecraft's signal. From Earth's southern hemisphere, the spacecraft will appear high on the horizon for about 12 hours at a time, allowing good data capture for long periods. NET was conducted while the spacecraft was over Australia.

One of the most critical radio science experiments will occur when the spacecraft passes behind the planet. As the radio signal passes through the planet's atmosphere, it will be bent slightly in the direction of the center of the planet. At any given time during the occultation, only one spot in the atmosphere will bend the radio beam precisely in the direction of the Earth. The spacecraft will track this critical spot by performing a series of pitch and yaw turns. The pointing must be exact. At Uranus, the limb tracking experiment will provide valuable information on the planet's atmosphere. For five hours, the spacecraft will use its internal gyros for spacecraft pointing, rather than celestial references.

Changes in the radio signal will also provide information on the rings as they pass between the Earth, the Sun, and the spacecraft. The spacecraft will use its S-band radio signal (which has a wavelength of 13 cm) at high power to study the atmosphere and its X-band signal (with a wavelength of 3.6 cm) at high power to study the ring particles. Since the output of the spacecraft's radioisotope thermoelectric generators (RTG's) is not sufficient to run both frequencies at high power at the same time, the X-band must switch from high to low power while the S-band high-power mode is being used for atmospheric measurements. Following the atmospheric occultation experiment, the X-band and S-band will be commanded back to their normal power levels of high and low, respectively.

NET included tests of these critical radio science events.

Late Stored Updates

"We have designed the 'movable block' so we can shift the timing of its execution by up to twelve minutes," explained Miner. "This is because the position and velocity of the spacecraft relative to the planet, its rings, and the satellites will not be known precisely enough until shortly before closest approach, when we can see the effects of gravity on the spacecraft's trajectory. Using radiometric and optical navigation data, the flight team will compute this positional data and transmit new instructions to the spacecraft just hours before the block begins. In addition, within the movable block, the timing of the radio science limb tracking maneuver can be shifted by up to 72 seconds."

"Although we had designed a movable block for Titan observations at Saturn, we were able to update that sequence *before* it was transmitted to the spacecraft. These instructions will be transmitted after the sequence is already resident in the spacecraft's computers," Miner concluded.

NET tested the flight team's ability to complete the late stored update activity, using the latest navigational data.

Best Lock Frequency

One of the operational quirks of Voyager 2 stems from the loss, in April 1978, of both the prime radio receiver and a tracking loop capacitor on the backup radio receiver. The failed capacitor makes it impossible for the spacecraft to track a changing radio signal. Worse yet, the "rest" frequency is very sensitive to temperature changes in the receiver.

The Voyager flight team has developed techniques for predicting the rest frequency as a function of time, translating that to a predicted transmit frequency as a function of time and Deep Space Station, and transmitting at the appropriate frequency under computer control. To further complicate matters, some spacecraft events, such as the X-band and S-band power switching mentioned above, switching other major power users on or off, or changing the spacecraft's attitude with respect to the Sun, have serious thermal effects on the receiver frequency. To combat this, periods from 24 to 72 hours are allowed after such events to permit the spacecraft's receiver frequency to stabilize before routine command transmissions are resumed.

"We are scheduled to uplink the post encounter computer sequences soon after completion of the near encounter activities," said Griffith, "and our ability to load these commands depends on our ability to track any frequency changes that occur during near encounter due to radiation, thermal effects, or doppler shifts."

A key effort during NET was to simulate as closely as possible the frequency changes that affect the ability to command the spacecraft. Only changes due to spacecraft power switching can be simulated; those due to radiation or doppler shift cannot.

Results

"The 'quick-look' assessment immediately following NET showed that the test objectives were met," said project manager Dick Laeser last Friday. "Moreover, the test served its purpose in flushing out some problems in the details. The timeline for the late stored updates is very tight and we encountered several problems in holding to the schedule. We may make some minor modifications to it before encounter. In addition, there were some procedural and ground system problems that will have to be fixed."

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Space Administration
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JPL 410-15-71 10/85

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Voyager Bulletin

MISSION STATUS REPORT NO. 72 NOVEMBER 4, 1985

Uranus Encounter Begins: Observatory Phase

On November 4, eighty-one days before Voyager 2 flashes past the seventh planet, Uranus, the Voyager flight team began continuous, extended observations of the Uranian system at better resolution than possible from Earth.

The one-ton spacecraft is now travelling at nearly 15 kilometers per second (relative to Uranus), and radio signals travelling at the speed of light take 2 hours 25 minutes to reach Earth, 2.88 billion kilometers away. Uranus lies 103 million kilometers ahead.

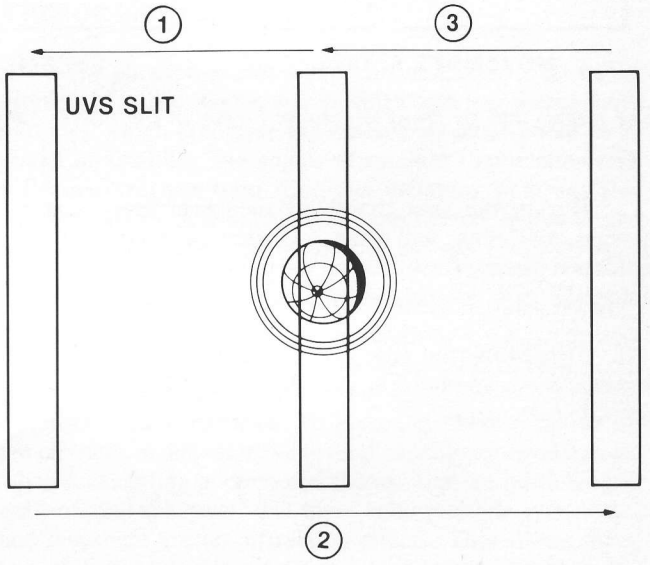
The first 67 days of the Uranus encounter period have been labeled the ''observatory'' phase. Some of what is learned during this time will be used to fine-tune the close-in observations. This phase will last until January 10.

Three computer loads have been designed to operate the spacecraft during the observatory phase. The first two will operate the spacecraft for almost one month each, the last for a week and a half.

During the observatory phase, the spacecraft's reference star will be Alkaid rather than Canopus, the usual reference.* The orientation of the spacecraft's roll axis determines what stars are seen in the background data of the ultraviolet spectrometer. If the spacecraft were using Canopus as a reference during this time, the spectrometer would see too much of the Milky Way. The use of Alkaid provides a less ''busy'' background.

The ultraviolet spectrometer will conduct daily searches for auroral emissions at the Uranian south pole, similar to the auroras (northern or southern lights) at Earth's poles. (Earth's auroras are caused by energetic particles spiralling into the atmosphere along magnetic field lines.) The UV spectrometer will also step across the Uranian system from one side to the other, looking for neutral hydrogen or other gases near the planet and its satellites. These system scans will occur twice daily, sweeping across a distance that will gradually shrink from 5 million kilometers to 260,000 kilometers by the end of the observatory phase.

In interplanetary cruise, the spacecraft maintains its orientation by using electro-optical devices that detect light from the Sun and a star, usually Canopus. This prevents the spacecraft from tumbling out of control. The sun sensor affects the spacecraft's pitch and yaw axes, while the star tracker affects the roll axis.



During the observatory phase, the ultraviolet spectrometer is scanning the Uranian system edge to edge, searching for clouds of neutral hydrogen or other gases.

The photopolarimeter will observe changes in the light reflected from the clouds as the planet rotates. These observations will lead to later high-resolution photometry of the planet.

Five times during the observatory phase, the imaging cameras will image the system for about 36 hours, or about two complete rotations of the planet (the rotation period has not yet been determined definitively). At a rate of 12 frames per hour, each of these imaging periods will yield about 400 frames, 80 percent of which will be taken by the narrow-angle camera.

''If we see features in the Uranian atmosphere that we can track, we may splice these frames together to create a short movie sequence such as the rotation movies obtained at Jupiter and Saturn,'' said Ellis Miner, Assistant Project Scientist. ''We only plan to do this if there is scientific value in such a movie.''

(For a rotation movie, the imaging is more or less continuous as the planet rotates. This differs from a ''zoom'' movie in which only a specific area is imaged as the spacecraft closes in.)

Most of the imaging sequences in the observatory phase will be relayed to Earth in real time rather than recorded for later playback.

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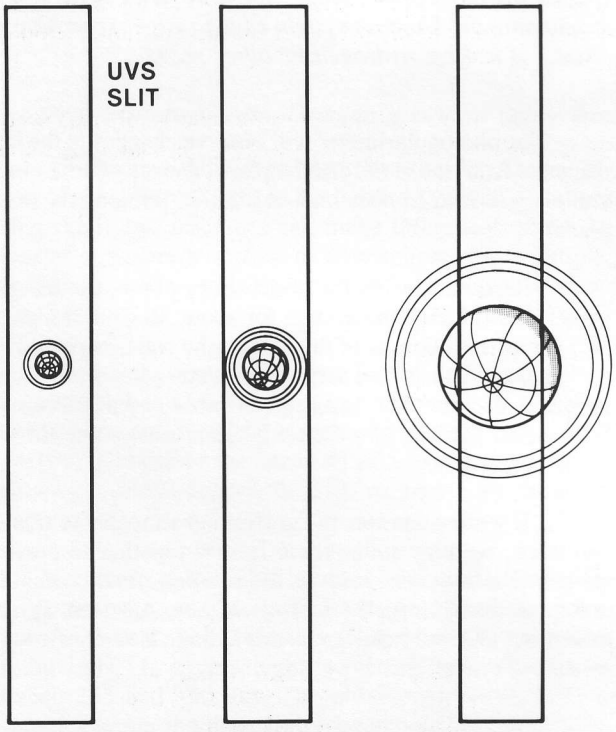
The planet and its rings will loom larger in the narrow-angle camera field-of-view as the spacecraft closes in.

During the first month of the observatory phase, several calibrations will occur, including calibrations of the fields and particles instruments, the radio frequency system's automatic gain control, and the antenna and sun sensor.

Torque margin tests will monitor the health of the spacecraft's scan platform, on which are mounted the four optical instruments.



The ultraviolet spectrometer is searching for auroral emissions at the planet's sunlit pole.

Uranus Science Experiments

Brief summaries of the Voyager's eleven scientific experiments will appear in the *Bulletin*.

Imaging

Each Voyager spacecraft carries a narrow-angle, 1500-mm reflector telescope (with an aperture of f/8.5) and a wide-angle, 200-mm refractor telescope (f/3) as part of their imaging subsystems, mounted on the spacecraft's steerable scan platform. Each camera has a vidicon (TV camera tube), shutter and filter assemblies, power supply, and support electronics.

Each image frame is an 800-line by 800-column array of picture elements (pixels) captured on a vidicon. Eight bits are used to describe each pixel's gray level, which can range from 0 (black) to 255 (white). The filters include ultraviolet, violet, blue, green, methane, orange, sodium, and clear. Color images are made by combining two or more images exposed through different filters. This is done on the ground in JPL's Multi-Mission Image Processing Laboratory (MIPL).

Due to Voyager 2's increased distance from Earth, the telecommunications capability at Uranus will be considerably reduced from what it was at Jupiter and Saturn. This poses problems for returning imaging data. Two techniques have been devised for coping with this imaging problem: data editing and data compression.

There are two options for data editing. When telemetry performance is down, full format frames will be returned, but some pixels will be systematically deleted, resulting in reduced resolution. The preferred option will be to return only part of the frame, but at full resolution.

In data compression, the brightness of each succeeding pixel is expressed as its difference from the preceding pixel. This technique reduces the total number of bits needed to transmit an image. Full resolution will be obtained, although the edges of a frame may be jagged if the imaged

scene is "busy." It is also possible to use only 7-bit encoding, reducing the gray-level resolution by a factor of two (0 to 127).

At Jupiter and Saturn, time-lapse movies of the systems were used to study the meteorology of the planets' atmospheres as well as properties of the satellites and rings. Seven 36-hour movie sequences are planned for Uranus as Voyager 2 approaches the planet. Each will show about two rotations of the planet so that scientists can observe changes in the atmosphere. By identifying specific features in the clouds and tracking them, wind speeds can be estimated. For example, at Saturn, equatorial wind speeds were found to be over 400 meters per second. In contrast, Earth's stratospheric jet streams blow at only 50 meters per second.

Complementary data among the infrared radiometer, the photopolarimeter, and the cameras will aid in determining the planet's heat balance by measuring the differences in brightness at different phase angles.

An "anti-smear" campaign has been implemented to reduce image blurring caused by long exposures (due to the low light levels at this distance from the Sun), combined with high relative velocities between the spacecraft and its targets, and the normal gentle swaying of the spacecraft. The spacecraft team has made changes in the spacecraft's attitude control system to reduce the natural spacecraft rates of rotational motion and, furthermore, to turn the spacecraft to match the speed of its target during selected imaging sequences targeted for the five known satellites. This latter technique, known as image motion compensation, is so effective that the resolution of the best satellite images will be increased by factors from 4 to 50 over what would be obtainable without image motion compensation.

The narrow Uranian rings will be imaged best by Voyager as the spacecraft crosses the ring plane and in occultation with high forward-scattering angles (i.e., when the rings are between the Sun and the spacecraft and appear backlit). The cameras will also be used to search for small satellites in and near the rings.

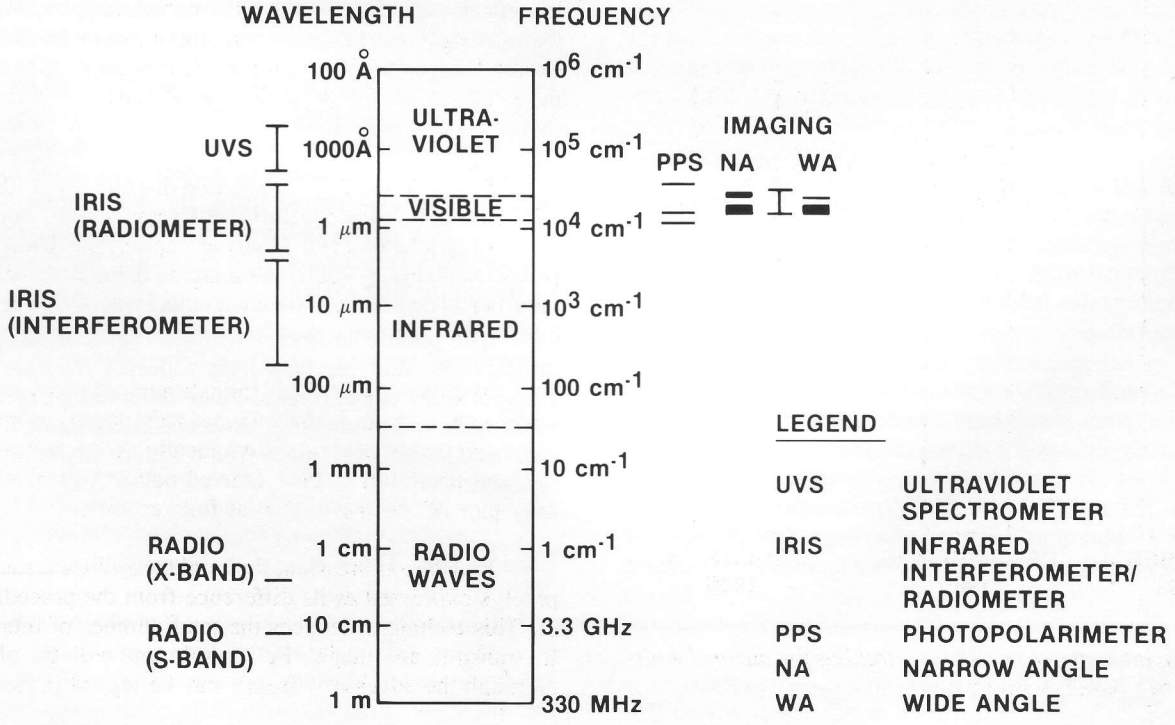
The team leader for imaging science is Brad Smith of the University of Arizona, Tucson. Twenty-two additional scientists make the imaging team Voyager's largest science team.

Photopolarimetry

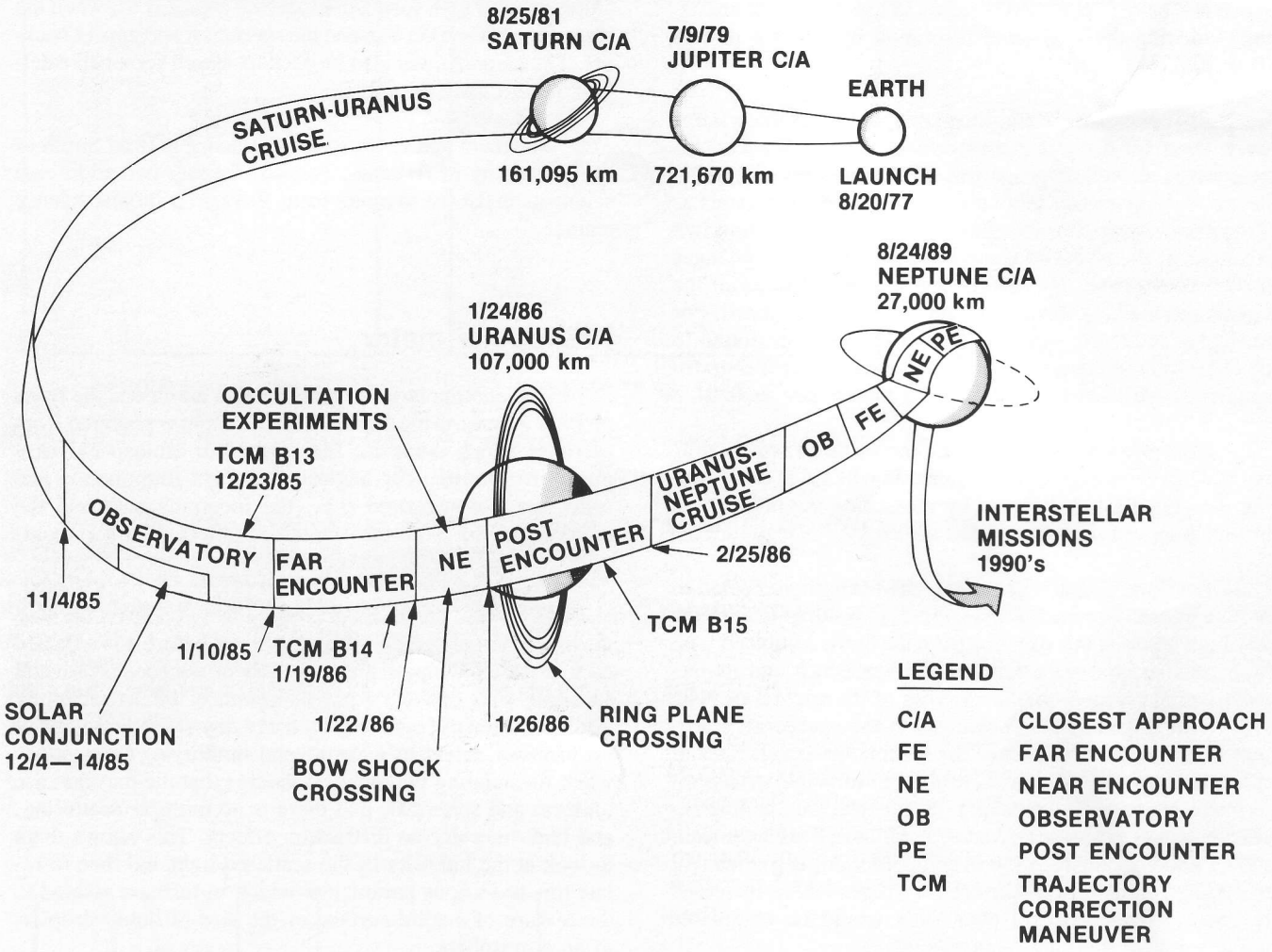
The photopolarimetry experiment addresses the basic problem of measuring the way in which light is scattered from particles which comprise the surface or atmosphere of a planet or satellite. The angles of sunlight illumination and reflection are measured (i.e., the incoming path and the emerging path). The intensity of the reflected light is measured as these angles change during the spacecraft flyby.

In reality, the problem is formidably complex because the light beam undergoes many processes before it is reflected back into the photopolarimeter: it may be bounced off several surfaces, pass through a gas or liquid, or be diffracted by different sizes of particles. To make any sense at all out of the problem, scientists make several simplifying assumptions when formulating photometric theory: that the particles are uniform and spherical, that there is no multiple scattering, and that there are no diffraction effects. This allows them to look at the intensity of the scattered light and then to relate this to various parameters which in turn are related to the texture of a solid surface or the size of liquid droplets in an atmosphere.

Light scattered through two media — air and water, for example — usually gains some polarization: the light



Voyager's science instruments provide complementary coverage in selected ranges of the electromagnetic spectrum.



Voyager 2 will observe the Uranian system at better than Earth-based resolution for about four months.

waves vibrate in a definite pattern. By studying the polarization of the reflected light as the lighting geometry changes during the flyby, scientists can make inferences about the nature of a planetary surface or atmosphere. For example, dark surfaces tend to have higher polarization at certain viewing geometries.

Because the photopolarimeter is very sensitive to small changes in light, the instrument can also be used to gain a better understanding of the nature of planetary rings. This is done by measuring the intensity of a background star as the starlight passes behind the rings as viewed by the moving spacecraft.

Mounted on Voyager's steerable scan platform, the photopolarimeter is a Cassegrain telescope with filters, polarization analyzers, and a photomultiplier tube to record incoming light. It covers eight wavelengths in the region between 235 and 750 μm. The photosensitive material in Voyager 2's photomultiplier tube has degraded, perhaps due to chemical changes. Another problem sometimes results in occasional errors in positioning of the instrument's aperture wheel. The photopolarimeter team has devised methods to use the instrument effectively despite these problems.

At Saturn, the photopolarimeter returned spectacular data on the rings by measuring the starlight passing through the rings from a distant star. The radial ring structure was determined to a resolution of meters. The same technique will be used at Uranus, using the star Sigma Sagittarii (Nunki), as it passes obliquely behind the outer rings, and the star Beta Persei (Algol) to determine the fine structure of the entire ring system.

The photopolarimeter will also observe the Uranian atmosphere, studying how light reflected from the clouds changes as the planet rotates. Phase observations at the satellite Titania will study reflectance and polarization — observations that cannot be made from Earth or any other present spacecraft.

Principal investigator for the photopolarimeter is Lonne Lane of JPL. There are six co-investigators.

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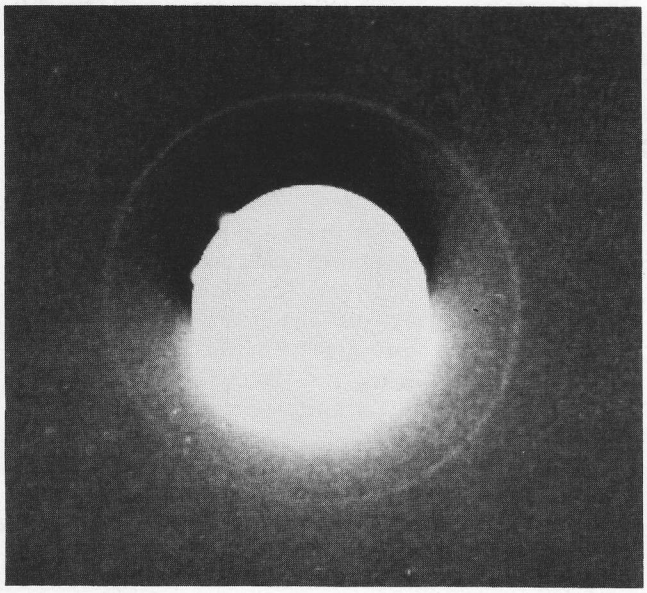
JPL 410-15-72 11/85

Status Bulletin Editor: Anita Sohus ..... (818) 354-4438
Public Information Office ..... (818) 354-5011
Recorded Mission Status ..... (818) 354-3051

Voyager Bulletin

MISSION STATUS REPORT NO. 73 DECEMBER 4, 1985



Uranus' epsilon ring is seen in this computer summation of six images returned on November 28, 1985 by Voyager 2's narrow-angle camera while still 72.3 million kilometers from the planet. The epsilon ring, some 51,200 kilometers from the planet's center, is the outer and most prominent of the planet's known nine rings. Because the ring is so narrow and dark, long exposure times were required to obtain a good image. Six images were added together by computer to produce this picture, which has an equivalent exposure time of 84.5 seconds. The central image of the planet is greatly overexposed. Artifacts due to electronic effects and image processing include the dark region just above the planet image, the diffuse brightening below it, and the small, bright projections from the edge of the planet in the upper right. The ring is distinctly less prominent in the lower left portion and more prominent in the upper right. This is in agreement with the predicted locations of the narrow and wide portions of this eccentric ring, respectively.

Early Results

Fifty-two days from its meeting with Voyager 2, a pipsqueak upstart of a robot from a distant planet called Earth, Uranus continues to swathe itself in secrecy. No cloud features are yet visible in images taken in late November. No radio emissions from the planet have been detected. The known satellites — Miranda, Ariel, Umbriel, Titania, and Oberon — obey the Keplerian laws of motion by faithfully circling the planet with monotonous regularity.

"Actually, it's an interesting evolving story," Voyager Project Manager Dick Laeser said of the planet's noncooperation. Uranus may be vastly different from the other gas giants (Jupiter, Saturn, and Neptune).

The only inroad has been successful imaging of the epsilon ring, the outer and most prominent of the planet's nine known rings. The epsilon ring is elliptical (eccentric), ranging from 20 to 100 km wide. The ring is also very dark, with a reflectance of only about 1 to 2 percent. Scientists speculate that its composition may be carbonaceous material similar to that of dark asteroids, or it may be radiation-darkened methane ice, perhaps like the dark side of Saturn's satellite Iapetus.

Color images from Voyager 2 show the planet itself to be aqua blue, but at the present resolution limit of about 1400 km per line pair the atmosphere remains featureless. At Jupiter and Saturn, scientists tracked the motions of atmospheric cloud features to determine atmospheric dynamics, wind speeds, and planetary rotation rates. Such studies at Uranus are thus far impossible.

"It's possible we can't look deep enough into the atmosphere to see ammonia cloud features," suggested Brad Smith, leader of Voyager's imaging team. Clouds visible in the atmospheres of the giant planets Jupiter and Saturn are composed of ammonia ice and usually form at about the same temperature on all planets. Since Uranus is so much colder than either Jupiter or Saturn, the ammonia clouds form deeper in the atmosphere and the imaging cameras may not penetrate the thick atmosphere above them. Water-ice clouds undoubtedly also exist at deeper levels in the atmospheres of the giant planets, completely hidden by the overlying ammonia-ice clouds. Atmospheric scientists are not totally disheartened, however, as Voyager 2's "eyes" may yet see atmospheric features. Voyager's cameras may discern thin methane clouds that form at levels higher than any ammonia clouds. In addition, vertical convective motion may carry some ammonia clouds upwards to where Voyager 2 might yet detect them.

Recent studies indicate that the helium abundance on Uranus may be as much as 40 percent that of hydrogen — nearly four times the hydrogen-to-helium ratios on Jupiter and Saturn. All planets supposedly started out with the same hydrogen-to-helium ratios at the formation of the solar system. Voyager Project Scientist Ed Stone suggests that at Uranus, much of the hydrogen may be combined with carbon and oxygen to form methane and water in the atmosphere and in a deep ocean layer beneath the atmosphere.

"Uranus is distant, almost invisible, and virtually unknown... In seven weeks we will see Uranus' unknown face, its rings, and its moons... The Voyager Project and Program teams deserve a lot of credit..."

Burton I. Edelson, NASA Associate Administrator for the Office of Space Science and Applications.

Magnetosphere Puzzle

Planetary scientists have come to expect that any planet possessing a magnetic field will be a radio source. Charged particles trapped within the planet's magnetic field (the magnetosphere) are swept around in space with the planet's rotation, producing radio emissions.

Jupiter is the strongest planetary radio source in the sky. In fact, Voyager's planetary radio astronomy experiment, which uses a pair of 10-meter-long "rabbit ears" to listen for radio emissions in space, detected Jupiter's radio signature the day the spacecraft was launched, while still 600 million kilometers away. Saturn's radio emissions were detected shortly after the spacecraft rounded Jupiter. Earth's natural radio emissions were detectable on the spacecraft until the spacecraft was beyond the orbit of Mars. Yet, no radio emissions have been detected from Uranus, generally thought to be similar in many respects to the gas giants Jupiter and Saturn.

"This suggests three possibilities," said Mike Kaiser, a member of Voyager's planetary radio astronomy team from Goddard Space Flight Center, Greenbelt, Maryland. "Uranus may have no magnetic field — or one so tiny that it doesn't form a magnetosphere. It may have a weak magnetic field with low frequency emissions or emissions only on the dark side of the planet. Or, it may be a totally bizarre planet."

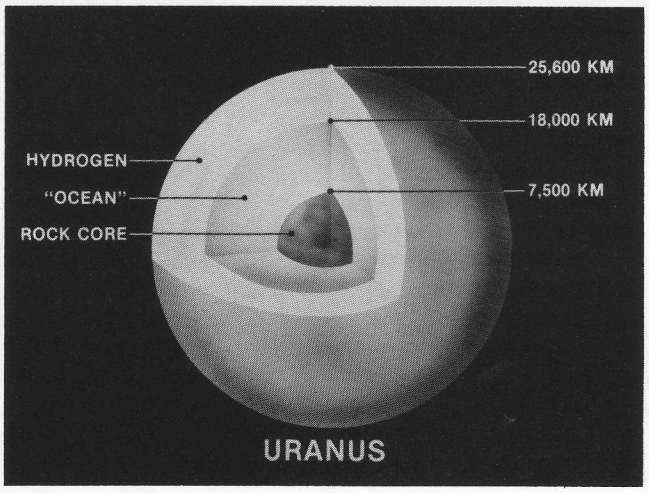
Dr. Stone carried the speculation further, suggesting that the magnetosphere may be similar to what was observed at the comet Giacobini-Zinner: there may be no bowshock (where the fast-traveling solar wind particles bump into slower particles captured in the planetary magnetosphere), but neutral hydrogen "boiling" off the planet may slow the supersonic solar wind and drag it past the planet.

Observatory Phase Continues

Voyager 2's ultraviolet spectrometer continues daily scans of the Uranian system to search for hydrogen or other gases near the planet, as well as daily searches of the south polar area for evidence of auroras caused by charged particles spiralling into the atmosphere along magnetic field lines.

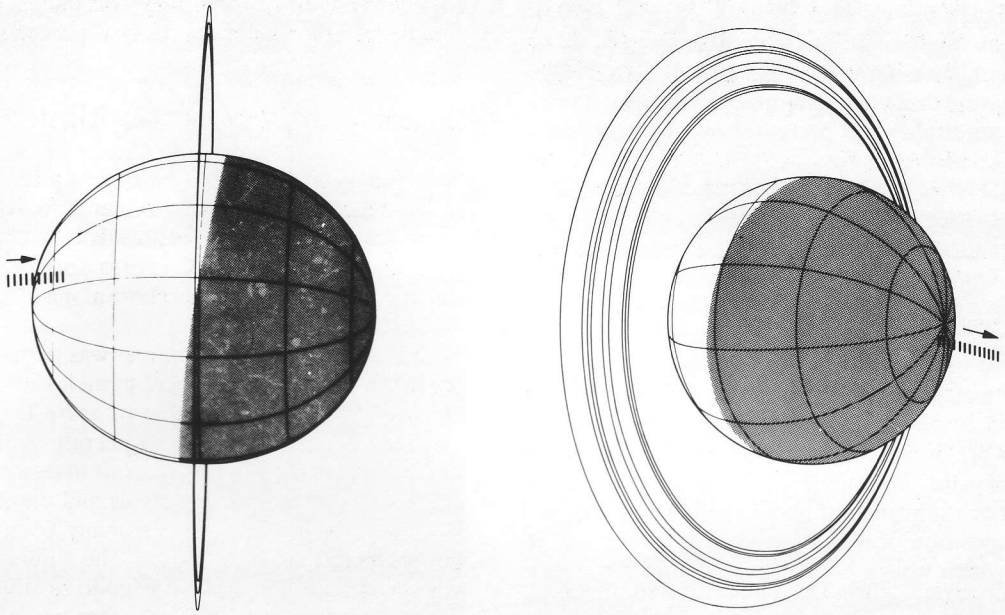
A "mini" cruise maneuver was performed on November 19 to allow the fields and particles instruments to scan the sky. The instruments that measure fields and particles are fixed in position on the spacecraft. A full-length cruise maneuver, in which the spacecraft maneuvers about its roll and yaw axes to allow the fields and particles instruments to view all of the sky, requires many hours and nearly fills the spacecraft's tape recorder. The "mini" cruise maneuver was designed many years ago to satisfy the needs of the fields and particles observers, yet to use only 40 percent as much time and tape recorder space as the full cruise maneuver.

The spacecraft has entered a ten-day period called "solar conjunction," when radio communications are hampered as the spacecraft and Earth are on directly opposite sides of the Sun. Solar radio emissions interfere with the radio signals from Voyager 2. As seen from the faster-moving Earth, the spacecraft appears to pass from left to right behind the Sun. Interference is greatest when the spacecraft is within 5° of the Sun. Spacecraft activities are designed to be at a minimum during such periods, which occur once a year. However, this geometrical alignment has been used for radio science studies of the Sun and of general relativity. Variations in the transmitted radio signal are studied as the signal passes close by the Sun. Solar conjunction also affords training opportunities for the operations people and equipment as preparations are made for the radio occultation experiments at Uranus, when radio communications with Earth will be severely reduced as the spacecraft passes behind the planet and its rings.



Uranus may have a rocky, Earth-sized core, overlain by an "ocean" of ice and a layer of molecular hydrogen. The temperature at the cloud tops is about 55 kelvins.

Uranus Science Experiments — Ultraviolet Spectrometry



To study the chemical composition of the atmosphere, the ultraviolet spectrometer will observe atmospheric effects on starlight from Gamma Pegasi as the star is occulted by the planet. The observation will be done at both the lit and dark poles during the near encounter in January.

The ultraviolet spectrometer measures the intensity of light in the extreme ultraviolet to far ultraviolet region of the spectrum. The optics of this instrument include 13 identical aperture plates which form a mechanical collimator (lenses will not transmit in the far ultraviolet), a reflection grating which spreads the light into its spectral colors, and a series of 128 fixed detectors which cover an ultraviolet wavelength range from 500 to 1700 angstroms. Detectable within this range are helium, sulfur, neon, argon, nitrogen, atomic and molecular hydrogen, oxygen, carbon, methane, acetylene, and ethane.

Mounted on Voyager's steerable scan platform, the instrument operates in one of two modes: occultation or airglow. The occultation mode measures the absorption and scattering of sunlight or starlight in an atmosphere as the spacecraft motion causes the Sun or star to disappear behind a planet or satellite. The airglow mode senses weak emissions high in the atmosphere due to bombardment by energetic particles or by resonant scattering of sunlight.

Three types of ultraviolet observations are planned at Uranus: system scans, disk measurements, and limb observations. Every day during the observatory phase, the aperture of the ultraviolet spectrometer will be stepped from one side of the Uranian system to the other, looking for a possible donut-shaped cloud (torus) of neutral hydrogen enclosing the planet. During these 75 days, the extent of the system covered in this scan will decrease from 200 R_U to 10 R_U. At one point, two observations will be done to mosaic the entire system out to 40 R_U from the planet in all directions. (R_U indicates the Uranian radius, about 25,600 kilometers.)

The ultraviolet spectrometer will mosaic both the sunlit pole and the dark pole to search for auroras. On Earth, auroras such as the Aurora Borealis, or Northern Lights, are caused by energetic particles spiralling into the atmosphere along the Earth's magnetic field lines. Auroras were found on both Jupiter and Saturn.

To determine the composition of the upper atmosphere, the instrument's aperture will drift across the bright limb of the planet. Polar occultations on both the lighted and dark sides will use the star Gamma Pegasi, more popularly known as Algenib. The effect of the atmosphere on the starlight will tell much about the chemical composition of the atmosphere. The instrument will similarly track the Sun as it disappears behind the planet, observing the absorption of sunlight by the atmosphere to determine the constituents and composition of the lower atmosphere.

The ultraviolet instrument will also observe the rings and try to determine if there is any diffuse material between the rings. These observations will be analyzed in conjunction with observations by the imaging cameras and the photopolarimeter.

During the 4-1/2 years since the Saturn encounter, the instrument has been extensively used for ultraviolet stellar astronomy observations. It has detected two new white dwarf stars, monitored cataclysmic variables (binary stars that closely circle one another), monitored cepheid variables (pulsating stars whose diameters change by as much as 20 percent in hours), established a consistent stellar flux scale for wavelengths below 1200 angstroms, and helped in mapping the energy distribution of a number of stars for wavelengths from 912 angstroms into the visible range of the spectrum.

The principal investigator for the ultraviolet spectrometry investigation is Lyle Broadfoot of the University of Arizona, Tucson. Thirteen scientists form an international team of co-investigators.

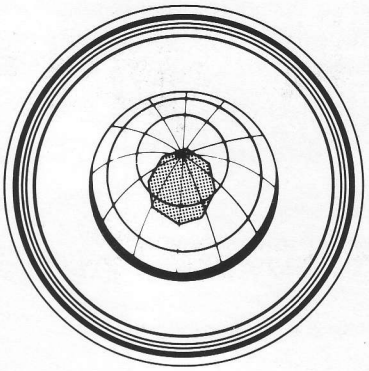
Infrared Interferometry and Radiometry

Every planet and satellite radiates infrared energy, determined by its temperature and atmospheric composition. Voyager's infrared interferometer and radiometer (IRIS) is designed to measure these temperatures, the molecular composition of an atmosphere (if present), and the reflectance of the body.

IRIS is an optical instrument mounted on Voyager's steerable scan platform. Light entering the instrument is split into two paths. One path leads to the radiometer, which measures light in the visible and near-infrared regions, while the other leads to the infrared (IR) interferometer. The radiometer measures the integrated reflected solar radiation and the interferometer measures radiation in the middle- and far-infrared portion of the spectrum. Inside the interferometer the light waves are divided and recombined after following slightly different paths. The interference pattern of the recombined light carries information about the temperature and molecular composition of the object viewed. A second interferometer, which uses a neon source within the instrument, is used as a reference to control the rate at which data are obtained by the main interferometer, and to provide a wavelength calibration.

On Voyager 2, the main infrared interferometer response slowly degrades while the instrument is at an operating temperature of 200 kelvins, apparently due to crystallization of elastic compounds in the instrument. A heater mounted on the primary mirror is used to warm the instrument and reverse the degradation. However, while this heater is on, the neon signal of the reference interferometer degrades. The neon signal gradually improves when the instrument is at its 200-kelvin operating temperature. Engineers must balance the conflicting temperature responses of these two parts of the instrument in order to use the instrument effectively.

The outer planets are a natural laboratory. Jupiter, with a 3° natural polar tilt, has little seasonal temperature differences between the northern and southern hemisphere. Saturn, tilted 27°, was 10° cooler at its north pole than at its south pole when the Voyagers flew by in November 1980 and August 1981. Scientists may see seasonal temperature differences between the northern and southern hemispheres of Uranus. The planet's polar tilt is a whopping 86°, and its south pole will be pointing almost directly toward the Sun when Voyager 2 flies by, while the north pole will be totally shadowed.

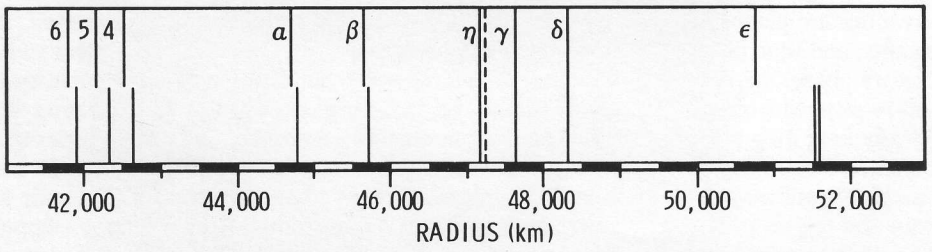


In this computer-generated drawing, the aperture of the IRIS instrument is overlaid on the planet's lit pole for composition studies of Uranus in the infrared.

The widths of the spectral lines of hydrogen are determined in part by the amount of helium in the atmosphere. These widths will be used to determine the ratio of hydrogen to helium. A high priority for IRIS will be to study the point in the atmosphere at which the radio signals to Earth will reappear as the spacecraft exits from behind the planet. This point will be studied nine hours before the occultation exit event. Combining the IRIS and radio science data sets will lead to a more precise determination of the hydrogen-to-helium ratio. This ratio will be compared to the ratios for Jupiter and Saturn and to abundances of these two elements predicted by theory for the primitive solar nebula.

Another prime objective of the IRIS experiment is to study the heat balance of Uranus. While the other giant planets, Jupiter, Saturn, and Neptune, all radiate more energy than they absorb from the Sun, ground-based measurements indicate that Uranus' radiation very nearly balances the solar input, making Uranus unique among the gas giants.

Principal investigator for IRIS is Rudy Hanel of NASA's Goddard Space Flight Center, Greenbelt, Maryland. There are ten co-investigators.



Three of Uranus' nine known rings — designated 6, 5, 4, alpha, beta, eta, gamma, delta, and epsilon — are very nearly circular, while the rest are somewhat eccentric. The epsilon ring also varies in width. Distances are given from the center of the planet.

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JPL 410-15-73 12/4/85

Public Information Office ..... (818) 354-5011
Recorded Mission Status ..... (818) 354-3051
Status Bulletin Editor: Anita Sohus ..... (818) 354-4438

Voyager Bulletin

MISSION STATUS REPORT NO. 74 JANUARY 13, 1986

A Sixth Moon Discovered

A new moon orbiting Uranus has been discovered in images taken by Voyager 2 on December 31, 1985.

Voyager imaging team scientists found the small moon in long-exposure images of Uranus and its rings taken by the narrow-angle camera. Conclusive evidence of the satellite's orbit was seen when the spacecraft was about 31 million kilometers from Uranus.

The new satellite, designated 1985 U1, is the sixth known to orbit Uranus. It is about 75 kilometers in diameter, and occupies an orbit 86,000 kilometers from the center of the planet, between the moon Miranda and the outermost of Uranus' nine known rings. The moon orbits Uranus every 18 hours, 17 minutes, 9 seconds.

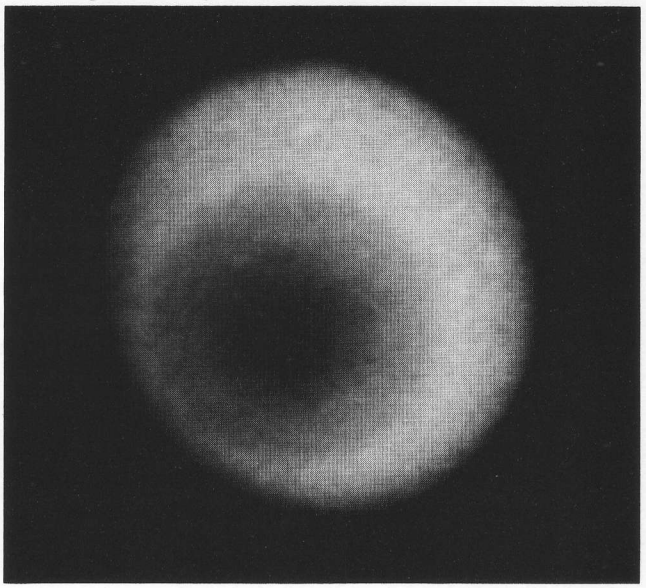
The spacecraft's flight path has been planned to pass between the rings and Miranda. The new moon will not be in a position to endanger Voyager 2 as it passes the planet.

Observatory Phase Ends, Far Encounter Begins

While the planet Uranus still appears to be a uniformly colored disk in the images received from the spacecraft, vague atmospheric features are now visible in specially processed images of Uranus's southern hemisphere. Multiple images taken in late November and December have been added together, computer-processed, and enhanced. The pattern is most pronounced in violet-filter images as a dark polar area surrounded by a grayish circle and then a whiter area. Assistant project scientist Ellis Miner speculates that the brightness difference may be due to a high-atmosphere polar haze that reflects less sunlight than the cloudy non-polar regions of the atmosphere.

Voyager 2's ultraviolet spectrometer has also seen the planet for the first time. The instrument first detected Uranus on December 18–19 at the hydrogen lyman alpha wavelength, 1216 angstroms.

The planetary radio astronomy instrument still has not detected natural radio emissions that were expected from the planet.



This Voyager 2 photograph of Uranus is the first picture to show clear evidence of latitudinal banding in the planet's atmosphere, and one of the first to indicate atmospheric structure of any sort. The computer-enhanced picture is a summation of five images returned December 27, 1985 by Voyager's narrow-angle camera. The spacecraft was 36 million kilometers (22 million miles) from Uranus.

The concentric pattern emanates like a bull's-eye from the planet's pole of rotation, which in this view lies left of center. (Uranus lies almost on its side with respect to the other planets and is rotating in a counterclockwise direction as seen here.) Clouds in the Uranian atmosphere give rise to the pattern, the first clear photographic evidence of banding similar to that seen previously on Jupiter and Saturn. The banding on Uranus, however, shows much less contrast. At the distance at which the images were acquired, Voyager's camera could have detected individual features as small as 660 kilometers (410 miles) across, but no such clouds or markings were apparent.

Scientists cannot yet say what properties — such as cloud height, composition or particle size — are giving rise to the varying levels of brightness visible here. The images composing this picture were shuttered through a filter that transmits only violet light. In the original, unprocessed images, the contrast of the features producing the banding is low, no more than 10 percent. In order to reduce "noise" and enhance the visibility of the features, processors at JPL combined five raw images and then compared the resulting composite to a hypothetical featureless planet illuminated by the Sun from the proper direction. Only the ratio between the original data and the hypothetical image is shown.

Daily system scans and auroral searches in the ultraviolet continue, along with various calibrations, computer checks, and optical navigation imaging. The "far encounter" phase began on January 10.

On December 23, the spacecraft performed a trajectory correction maneuver, firing hydrazine gas from its thrusters for 14.5 minutes to adjust its aimpoint at Uranus by about 340 kilometers. The spacecraft was accelerated by 2.1 meters per second. The change in aimpoint was necessitated by a refinement in the knowledge of the mass of the planet, which is now believed to be 0.3 percent larger. This upward shift was necessary to better fit recent optical navigation data. Greater mass translates to greater gravitational effects on the spacecraft's flight path, so the aimpoint was moved farther from the planet.

As a result, the flight team is making minor yet important changes in the near encounter sequences since the approach geometry and the relative timing of specific events will change slightly. For example, closest approach to the satellite Miranda will occur 92 seconds earlier than previously planned. Since the spacecraft will be tracking the satellite to reduce image blurring, the spacecraft's antenna will be pointed away from Earth and thus there will be no communications link at that time. However, it will be important to regain the communications link quickly in order to use the radio data to determine the mass of Miranda.

A trajectory correction maneuver will be made January 19, to fine tune the approach to Uranus.

Uranus Science Experiments – Planetary Radio Astronomy

The planetary radio astronomy (PRA) team works with a remote-sensing instrument designed to detect radio emission signals. Two 10-meter-long whip antennas are mounted on the spacecraft bus at a 90° angle to maximize the directivity of the antennas. The planetary radio astronomy and plasma wave experiments share the same antennas and their electronics are mounted piggyback.

During the past years of cruise to Uranus, the PRA team has been studying solar radio emissions. Voyager 2 makes an effective solar radio observatory partly because of its longevity. Although solar activity is currently at a low in its cycle, Voyager 2 has detected several solar flares in the last year and uses them for calibrations.

At Uranus, the PRA will be listening for radio emissions from the planet. Such signals come from synchrotron emission in the planet's magnetic field and can thus be used to measure the rotation rate of the planet's core. The PRA will also measure radio emissions from auroras, phenomena that at Earth are caused by charged particles spiralling into the atmosphere along Earth's magnetic field lines. Static electricity and lightning may also be detected in the Uranian atmosphere. Radio emissions may be detected as the spacecraft crosses the ring plane, as well.

Principal investigator for planetary radio astronomy is Jim Warwick of Radiophysics, Inc., Boulder, Colorado. There are 14 co-investigators.

Plasma Waves

The plasma wave subsystem (PWS), using the same antennas as the planetary radio astronomy subsystem, is a local sensing instrument (i.e., it senses radio signals and phenomena in the immediate vicinity of the spacecraft rather than at a great distance).

The plasma wave instrument will detect and measure plasma wave interactions in the magnetosphere and detect interactions between the solar wind and the planet's magnetosphere. It can detect particles in the ring plane and measure their spatial density. It also measures continuum radiation, chorus, and ion acoustic waves in the magnetosphere, lightning and whistlers in the atmosphere, and upper hybrid resonances and electron plasma oscillations.

Studies of the planetary fields and particles environment are esoteric to many people, and Voyager scientists continue to look for ways to make their data more meaningful to the lay person. Data from the PWS can be processed by JPL's Multi-Mission Image Processing Laboratory so that phenomena not easily visible in black and white displays stand out in color. An example of this is the whistler phenomenon found in the atmospheres of Jupiter and Saturn. In addition, the signal from the PWS can be played audibly. The instrument is so sensitive that it detects electronic switching in other instruments on the spacecraft. In audio tapes, one can hear the thrum of the spacecraft's main power supply, the ping as attitude control thrusters fire, and the ringing as other instruments operate. As the spacecraft dived through the ring plane at Saturn, the PWS received signals that sound in the audio tape as though the spacecraft were being pelted with driving rain.

Both Voyager spacecraft are also looking for the heliopause, the edge of the Sun's magnetic influence. By some definitions, this is the edge of our solar system. PWS data in late 1983 and early 1984 indicate that Voyager 1 may be nearing this boundary, and may cross it as early as 1991; other estimates of the heliopause location would place Voyagers 1 and 2 passing this boundary closer to the end of the century. Voyager 1's flight path is taking it above the ecliptic plane at an angle of about 35°. Although Pioneer 10 is now the farthest spacecraft from the Sun, it is heading down the Sun's magnetotail and is not expected to exit the heliosphere in that direction for decades.

Principal investigator for the plasma wave investigation is Fred Scarf of TRW, Redondo Beach, California. There are two co-investigators.

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JPL 410-15-74 1/86

Status Bulletin Editor: Anita Sohus ..... (818) 354-4438
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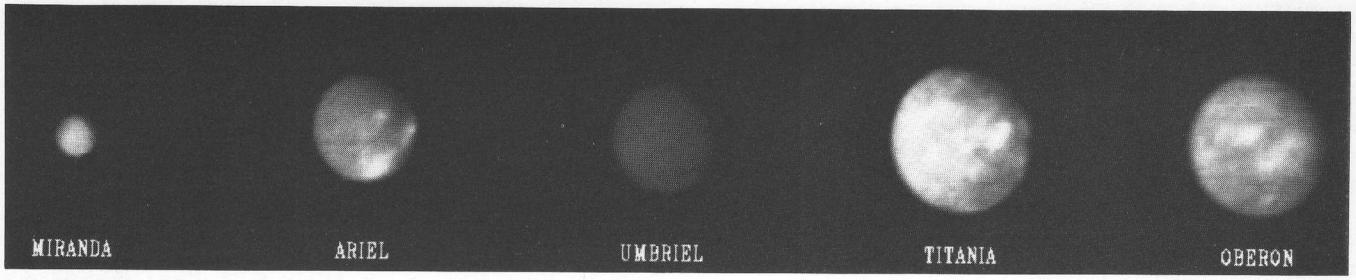
Voyager Bulletin

MISSION STATUS REPORT NO. 75 JANUARY 22, 1986

Many Moons . . .

As Voyager 2 closes in on Uranus, the number of known moons is rapidly increasing. In addition to the small moon discovered in December, eight additional small moons – including two flanking the epsilon ring – have been confirmed in long-exposure images designed to search for such objects. Six are 30 to 50 kilometers in diameter, and orbit between the outermost known ring (the epsilon ring) and the heretofore innermost known moon Miranda. All are also inside Voyager's trajectory. The two moons near the epsilon ring are called "shepherding" moons because of the theory that such moons "herd" ring particles between them. Voyager scientists expect to find more Uranian satellites, both in and around the rings, during the next two weeks of the flyby.

For now, all will carry official numerical designations, until the nomenclature committee of the International Astronomical Union recommends names for them and names are approved at the IAU Congress in several years. Until then, for example, the first Uranian moon discovered in 1986 will be designated 1986 U1.



This "family portrait" of Uranus' five largest moons was compiled from images sent back January 20 by Voyager 2. The pictures were taken through a clear filter from distances of 5.0 million to 6.1 million kilometers (3.1 million to 3.8 million miles). The relative sizes and reflectivities of the satellites are shown. From left, in order of decreasing distance from the planet, they are Miranda, Ariel, Umbriel, Titania and Oberon. The two largest, Oberon and Titania, are about half the size of Earth's moon, or roughly 1,600 kilometers (1000 miles) in diameter. Miranda, the smallest of the five, has about one-quarter to one-third the diameter. Even in these distant views, the satellites exhibit distinct differences in appearance. On average, Oberon and Titania reflect about 20 percent of the incident sunlight, Umbriel about 12 percent, Ariel and Miranda about 30 percent. Ariel shows the largest contrast on its surface, with the brightest areas reflecting 45 percent of the incident sunlight, the darkest areas about 25 percent. All five satellites show only slight color variations on their surfaces, with their average color being very nearly gray.

Engineering Update

The trajectory correction maneuver scheduled for January 19 was canceled since the flight path was deemed satisfactory without further refinements. Deletion of the maneuver allowed more tracking data to be gathered for final updates to the timing and pointing of critical observations near closest approach on January 24.

The final pre-encounter torque margin test on January 20 showed the azimuth and elevation actuators of the steerable scan platform to be in good health. The azimuth actuator had caused the platform to stick shortly after the spacecraft's closest approach to Saturn in August 1981, and several years of analysis and testing on the ground and in-flight followed. Torque margin tests are run periodically to detect any degradation in actuator operation. Had such degradation been apparent, plans had been developed to point the platform-mounted instruments during the most critical near-encounter sequence by rolling the spacecraft rather than moving the scan platform. Four optical instruments ride on the platform.

A problem in one of the spacecraft's onboard computers was worked around on January 20 by transmitting a patch to bypass a discrete bit in memory of the secondary Flight Data Subsystem – the unit that performs image data compression. The problem, inversion of one bit in one word of the memory, caused apparent streaking of the images as they were displayed. The cause of the problem was apparently a single word memory failure. All data was recorded on Earth, and all information is expected to be recovered. Only imaging data was affected.

Deep Space Network

The Uranus encounter presents an unprecedented challenge in deep space communications. The Voyager X-band radio signal, for example, will be less than one-sixteenth as strong as it was at Jupiter in 1979, due to the enormous distance the spacecraft has travelled. NASA's Deep Space Network (DSN), operated by the Jet Propulsion Laboratory, has tracked and communicated with U.S. deep space probes since 1962.

DSN stations are located around the world in multiantenna complexes at Goldstone in California's Mojave Desert; near Madrid, Spain; and near Canberra, Australia. The three complexes are spaced at widely separated longitudes so that spacecraft can be in continuous view as the Earth rotates.

The DSN has just undergone a major upgrade adding, among other things, new 34-meter antennas and automatic network monitor and control. A new baseband signal-combining system called "arraying" has also been developed to optimize the weak telemetry signal received at two or more antennas. Each station uses its 64-meter (210-ft) antenna and 34-meter (112-ft) antenna for deep space communication. (The sizes refer to the antenna dish.) In addition, high-efficiency 34-meter antennas have been added at Goldstone and Canberra, and another is scheduled to begin operations at Madrid in March 1987.

The structure of a 64-meter antenna is 21 stories high and weighs nearly 8,000 U.S. tons. The rotating portion, which weighs more than 3,500 U.S. tons, floats and moves on a thin film of hydraulic oil about 0.2 millimeters thick. Despite its size, the antenna, with its complex electronic equipment and unique mechanical systems, is a precision instrument capable of communicating with spacecraft at the edge of the solar system. The maximum tracking velocity is 0.25° per second. Pointing accuracy is about 0.005°.

In addition to the giant antennas, signal processing centers at each complex house equipment for transmission, reception, data-handling, and interstation communication. The downlink radio frequency system includes cryogenically cooled, low-noise amplifiers.

Spacecraft commands are sent from JPL to the ground stations via data lines, microwave links, and satellite links. At the stations, the uplink to the spacecraft operates at the S-band radio frequency (2,113 megahertz). The 64-meter antennas have 400-kilowatt transmitters which are normally operated at 60 kilowatts for Voyager.

The Voyager data rate is shrinking due to the increasing distance between Earth and the spacecraft, so modifications have been made both on the ground and on the spacecraft. At Jupiter, 5 AU* from the Sun, the maximum data rate was 115.2 kilobits per second (kbps) using the spacecraft as built and the 64-meter tracking antennas. At Saturn, at 10 AU, the maximum data rate dropped to the 44.8 to 29.9 kbps range, even with the addition of some antenna arrays. At Uranus, at 20 AU, the maximum data rate range is 21.6 to 14.4 kbps. The spacecraft uses a more efficient data encoding scheme and image data is compressed by transmitting only the difference in brightness between adjacent picture elements (this technique, called image data compression, requires less than half as many bits to transmit an image). In addition, the DSN arrays its antennas on a regular basis for Voyager, and with the negotiated support of the 64-meter Parkes Radio Astronomy Observatory (operated by the Australian Central Science and Industry Research Organization), the Canberra complex can array four antennas. At Neptune, the data rate is expected to hold steady at 21.6 to 14.4 kbps by enlarging the 64-meter antennas to 70 meters, adding a high-efficiency 34-meter antenna in Madrid, and negotiating support for short periods from other agencies.

At the Uranus encounter, all DSN antennas at each longitude will be arrayed, so that their combined collecting areas will increase the amount of signal captured and thus improve the potential for high-rate low-error data return.

Arraying the antennas almost doubles the collecting area and increases the expected signal strength to one-half – instead of one-fourth – the Saturn level when Voyager 2 reaches Uranus.

Australian activities will be critical to encounter support, because the high southern (-23 degree) declination of Voyager 2 will result in long (up to 13 hours) spacecraft view periods at Canberra and Parkes. Large distances between the Parkes and Canberra antennas decrease the risk of lost data due to local weather conditions, as X-band radio signals are very sensitive to atmospheric water vapor.

The combined Canberra–Parkes facilities will obtain the critical closest-approach imaging and science data for Uranus and all its satellites on January 24, in addition to data recorded on the spacecraft and played back over the next several days. This Canberra–Parkes array is expected to obtain various telemetry data during closest approach and all radio science data during the critical Uranus and ring occultation periods on January 24, encounter day.

**An astronomical unit (AU) is the distance between Earth and the Sun – about 150,000,000 km (93,000,000 mi.).*

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Pasadena, California
JPL 410-15-75 1/86

Status Bulletin Editor: Anita Sohus ..... (818) 354-4438
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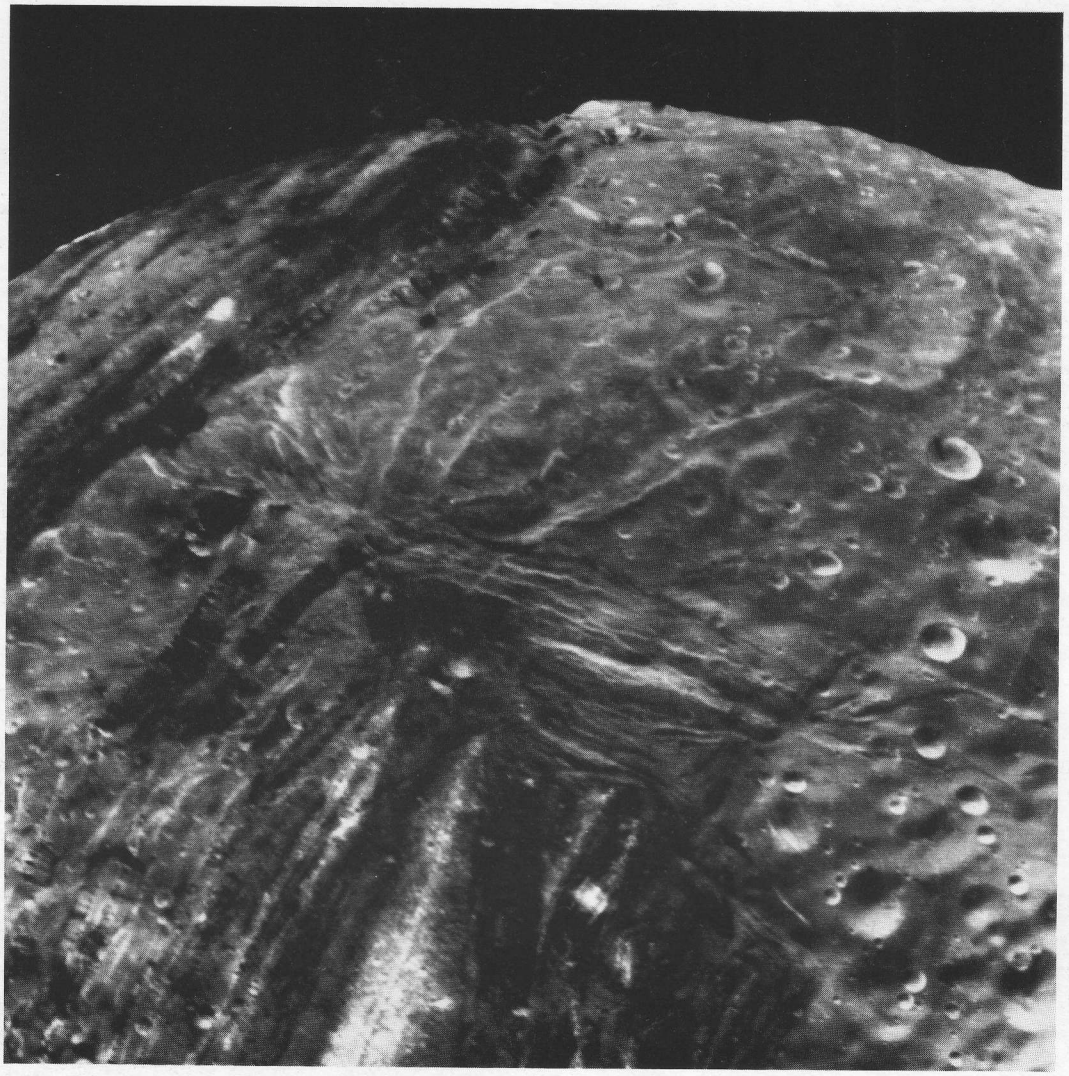
Recorded Mission Status ..... (818) 354-3051

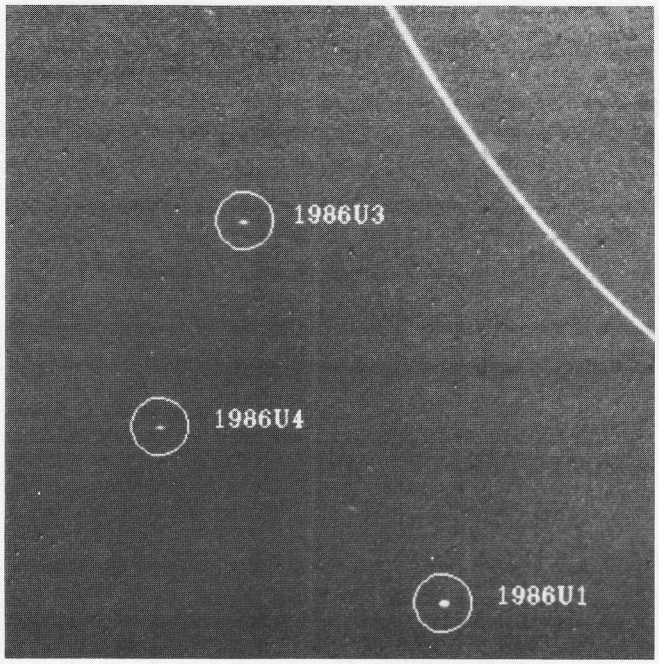
Voyager Bulletin

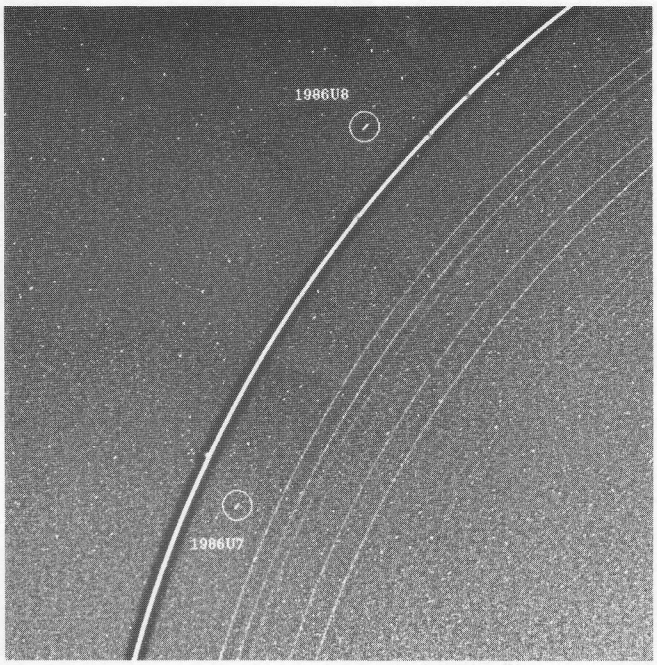
MISSION STATUS REPORT NO. 76 JANUARY 26, 1986

Miranda!

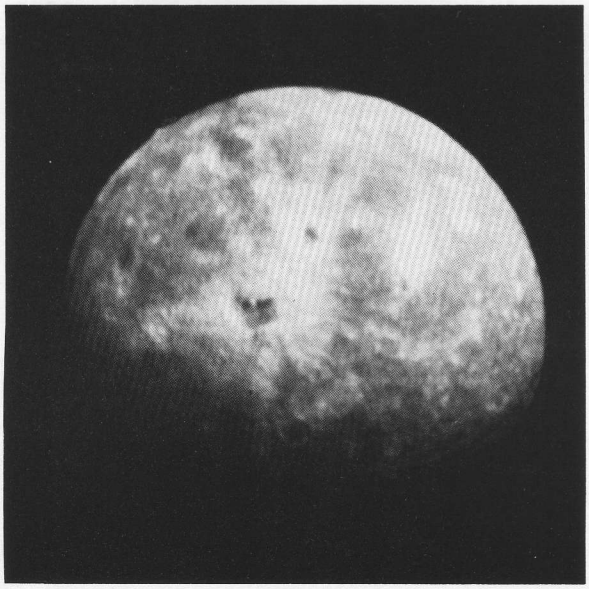


Uranus' innermost large moon is a hybrid of the most bizarre geologic forms in the solar system, including the valleys and flows of the planet Mars, the compression faults of the planet Mercury, and the grooved terrain of Jupiter's satellite Ganymede. Here, a slab region is bordered by a deep trench that goes beyond the limb, with scarps and sawtooth terraces. Old terrain showing tectonic features with many kinds of faults borders cratered areas that have undergone impact gardening by meteor bombardment long ago. This incredible picture is part of an eight-frame mosaic made January 24 as Voyager 2 raced past the 500-km (310-mi) diameter moon at 65,000 km (40,000 mi) an hour, tracking the satellite's motion. The light levels at Uranus, two billion kilometers from the Earth, are one quarter of one percent as much as at Earth, requiring long camera exposures which would result in badly smeared images were it not for engineering changes made to the spacecraft over the past several years. Voyager 2 also flew closer to Miranda than to any other body it has visited. Features as small as 600 meters (one-third mi) can be seen in this image, taken at a distance of 31,000 kilometers (19,000 miles).





Several moons newly discovered by Voyager 2 are shown in these images. At left, three of the newly discovered satellites of Uranus are captured in this image taken January 18, 1986, when the spacecraft was 7.7 million kilometers (4.8 million miles) from the planet. All three lie outside the orbits of Uranus' nine known rings, the outermost of which, the epsilon ring, is seen at upper right. Long exposures were required to detect these small objects; thus, as a result of the relative motions of the spacecraft and the moons, they appear slightly elongated. At right, two "shepherd" satellites associated with the rings of Uranus are shown. The two moons – designated 1986U7 and 1986U8 – are seen here on either side of the bright epsilon ring; all nine of the known Uranian rings are visible. The image was processed to enhance narrow features. The epsilon ring appears surrounded by a dark halo as a result of this processing; occasional blips seen on the ring are also artifacts. Lying inward from the epsilon ring are the delta, gamma and eta rings; then the beta and alpha rings; and finally the barely visible 4, 5 and 6 rings. Since their discovery in 1977, the rings have been studied through observations of how they diminish the light of stars they pass in front of. This image is the first direct observation of all nine rings in reflected sunlight. They range in width from about 100 km (60 mi) at the widest part of the epsilon ring to only a few kilometers for most of the others. The discovery of the two ring moons 1986U7 and 1986U8 is a major advance in understanding the structure of the Uranian rings and is in good agreement with theoretical predictions of how these narrow rings are kept from spreading out. Based on likely surface brightness properties, the moons are of roughly 20- and 30-km diameter, respectively.



OBERON

A large crater with a bright central peak stands out near the center of Oberon's disk in Voyager 2's best picture of Uranus' outermost moon. The floor of the crater is partially covered with very dark material. This may be icy, carbon-rich material erupted onto the crater floor sometime after the crater formed. Another striking topographic feature is a large mountain, about 6 kilometers (4 miles) high, peaking out on the lower left limb. Several large impact craters on the icy surface are surrounded by bright rays similar to those seen on Jupiter's moon Callisto. The picture was taken on January 24, 1986, from a distance of 660,000 km (410,000 mi). The color was reconstructed from images taken through the narrow-angle camera's violet, clear and green filters.

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National Aeronautics and
Space Administration
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Pasadena, California
JPL 410-15-76 1/86

Status Bulletin Editor: Anita Sohus ..... (818) 354-4438
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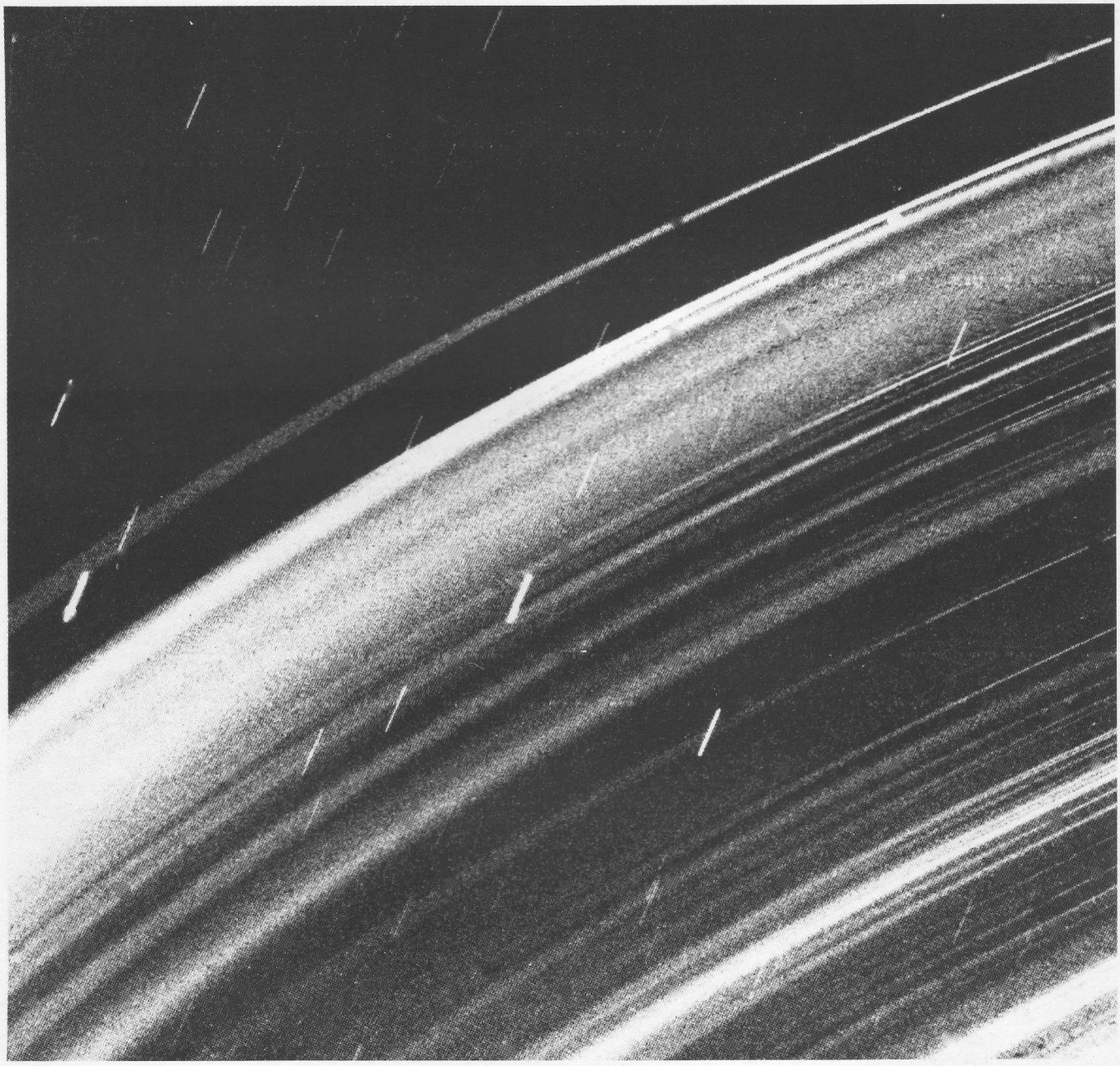
Voyager Bulletin

MISSION STATUS REPORT NO. 77 FEBRUARY 5, 1986



Small particles are distributed continuously throughout the Uranian ring system, although most ring particles are larger than 1 meter across. Voyager 2 took this image while in the shadow of Uranus, at a distance of 236,000 kilometers (147,000 miles) and a resolution of about 33 km (20 mi). This unique geometry – the highest phase angle at which Voyager imaged the rings – allows us to see lanes of fine dust particles not visible from other viewing angles. All the previously known rings are visible here; however, some of the brightest features in the image are bright dust lanes not previously seen. The combination of this unique geometry and a long, 96-second exposure allowed this spectacular observation, acquired through the clear filter of Voyager's wide-angle camera. The long exposure produced streaks due to trailed stars as well as a noticeable, non-uniform smear.

Navigation

Voyager 2 traveled an arc of nearly 5 billion kilometers to Uranus, yet engineers estimate the actual closest approach to have been within 20 kilometers of where they thought they would be.

"Uranus was a navigational challenge for several reasons," explained Bill McLaughlin, manager of Voyager's Flight Engineering Office. "First, we had no data from previous spacecraft to guide us to Uranus.

"Second, Uranus is so far away that it was difficult to measure the satellite positions from Earth and obtain accurate *a priori* orbits that could be refined by spacecraft measurements."

"And third, Uranus lies on its side, making triangulation difficult and presenting a different navigational situation than we have dealt with before," McLaughlin concluded. As the spacecraft approached the planet, there was an element of the unknown in exactly where the ship was in relation to the plane of the planet, rings and satellites. Even a small navigational error could have resulted in pictures of deep space rather than the intended target, for example. In addition, the spacecraft had to pass through a specific region just inward of Miranda to be able to use Uranus' gravity to slingshot itself on to Neptune.

"We don't know perfectly where the spacecraft is," says Don Gray, Voyager's Navigation Team Chief, "but we know within kilometers."

The Voyager flight team uses four navigational tools: optical navigation and three radio techniques – Doppler, ranging, and a version of very-long baseline interferometry (VLBI).

Navigating by the Stars

"During the approach phase, optical navigation is the most precise way to determine the spacecraft's position in relation to a planet," explained optical navigation engineer Bill Owen.

Engineers use Voyager's images of known star fields to determine the spacecraft's location. The targeting of the images is designed to include a known star in the same field of view as a planet or satellite. Lick Observatory at the University of California, Santa Cruz, provides up-to-date star positions based on astrographic plates requested by JPL's opnav engineers. This information is stored in computers and compared with optical navigation frames sent down by the spacecraft.

Software developed since the Saturn encounters allows engineers to manipulate the data for easier analysis. For example, one can zoom in on (enlarge) a small set of pixels (picture elements) out of the total 800 by 800 array. One can also stretch the original gray scale of 256 levels to make small variations about a given level easily visible for analysis.

Currently, Voyager's backdrop is the constellation Sagittarius, in the middle of the Milky Way, so there are many stars suitable for use in optical navigation. Most are dim – about eighth or ninth magnitude.

In the Uranus encounter period, from November 4, 1985 through February 25, 1986, nearly 250 optical navigation pictures will be taken, usually with 1.44-second exposures. This data is correlated with other tracking data and used to update the pointing and timing of critical science observations.

Optical navigation is also used to determine the satellite orbits. By measuring the center of the satellite and the location of known stars in successive images, engineers can infer the satellite's position and thus determine its orbit.

Navigating by Radio

"Radio data usually best determine the spacecraft's position relative to Earth. However, in the last few days before closest approach to a planet, powerful planet-relative information becomes available due to a strong gravitational signature in the data. In the case of Uranus, this occurred within five days of closest approach," explained Tony Taylor, lead orbit determination analyst.

The spacecraft's direction and velocity is determined by measuring the Doppler shift. Doppler is a shift in frequency caused by relative motion between the source and the receiver (a familiar, audible Doppler phenomenon is the change in pitch heard as a locomotive bears down upon and then sweeps past a stationary observer.) One-way Doppler measures the downlink signal from the spacecraft's ultrastable oscillator electronics, while two-way Doppler measures the change in a signal uplinked from Earth, received at the spacecraft, changed in frequency by a prespecified amount, and downlinked back to Earth.

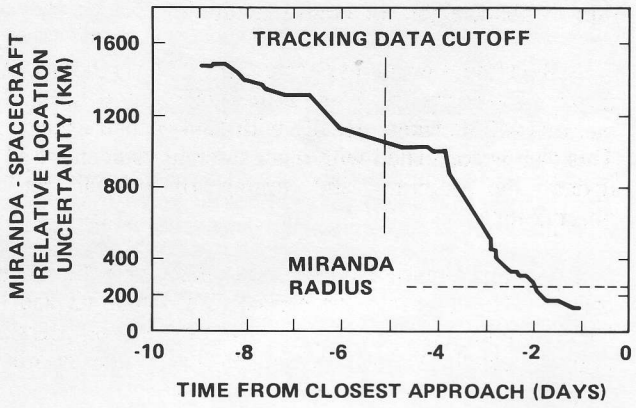
The distance, or range, from Earth to the spacecraft can be determined by measuring how long it takes for a coded signal to travel from Earth to the spacecraft and back to Earth.

Voyager also uses a version of very-long baseline interferometry called delta differential one-way ranging (ΔDOR). Two ground stations observe the spacecraft, note the difference in time of signal receipt as the Earth rotates, and then slew simultaneously to a quasar and again measure the difference in time of signal receipt. These results are then differenced (hence the "delta differential" in the name) and from this, the angle of the spacecraft with respect to a line between the two stations is calculated. Doppler and ranging together with ΔDOR give a good three dimensional knowledge of the spacecraft's position.

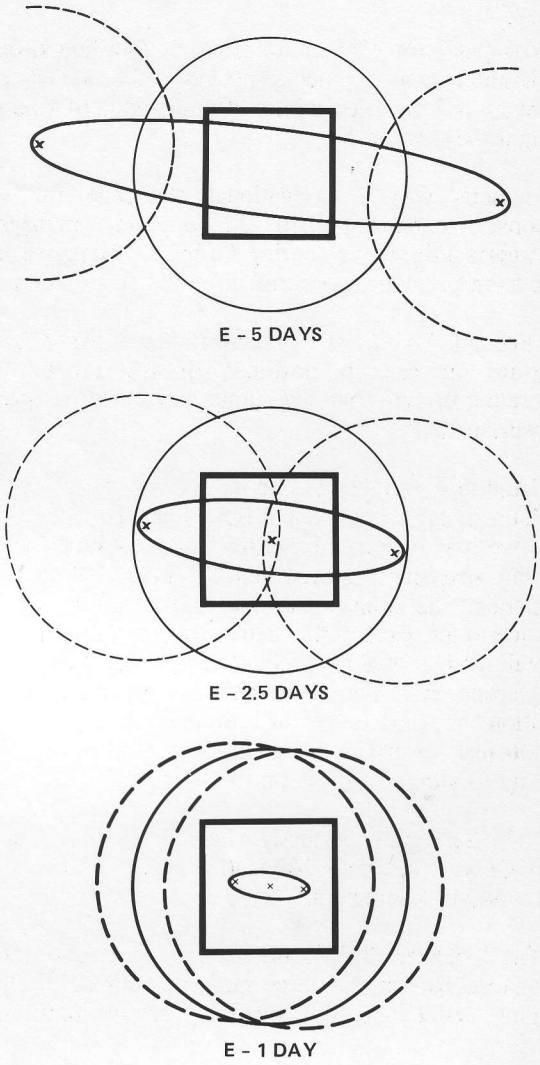
A combination of these four navigational tools is used to guide the spacecraft, to deliver it to the right place at the right time, and then, after the fact, to reconstruct the actual flight path followed.

Maneuver Design

Once the spacecraft's position is estimated and a target aimpoint is selected, the Navigation Team determines what change is needed in the spacecraft's velocity to arrive at the right place at the right time. The Spacecraft Team then



Voyager 2 had a depth perception problem as it approached the Uranian system, since the orbital plane of the Uranian moons was perpendicular to the flight path. The possibility of mispointing the science instruments was very real, and it was imperative to incorporate the latest tracking data possible, both Doppler radiometric data sensing the gravitational tug of the planet and optical navigation pictures. Plans were devised and carried through to use tracking data obtained as late as one day before closest approach and to modify the spacecraft's instructions after the instructions had begun to be carried out. The above chart shows that if the data cutoff had been five days before closest approach, the uncertainty in the pointing would have been much larger than the satellite Miranda, and the satellite might have been missed altogether. By sending late updates to the spacecraft, the uncertainty was narrowed to an acceptable level, as shown in the sequence at right. The square represents the field of view of the narrow-angle camera; the solid-line circle represents Miranda; the ellipses represent the size of the uncertainty; the X's represent the center of Miranda; and the dashed-line circles indicate where Miranda would have been at various uncertainty points. In fact, the final orbit determination was so accurate that spectacular images of Miranda were returned.



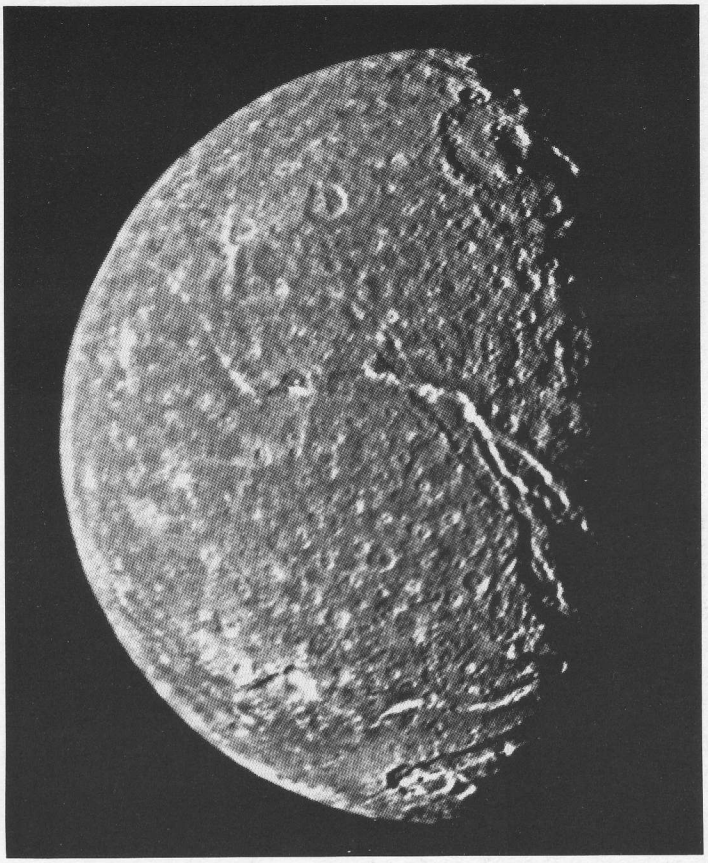
designs a trajectory correction maneuver using the spacecraft's attitude control and propulsion subsystems. Finally, the Sequence Team translates this design into instructions for the spacecraft's computers. Course corrections may be small, such as the 14.5-minute burn performed on December 23 (which used about 2.1 pounds of hydrazine propellant and accelerated the craft by 2.1 meters per second), or large, such as the 2-1/2-hour burn on February 14 which will impart an acceleration of 21.1 meters per second to the spacecraft. (The spacecraft is currently travelling at about 18 kilometers per second.)

"The February 14 trajectory correction will set up the correct timing for a good look at Neptune's big satellite Triton in August 1989," noted Gray.

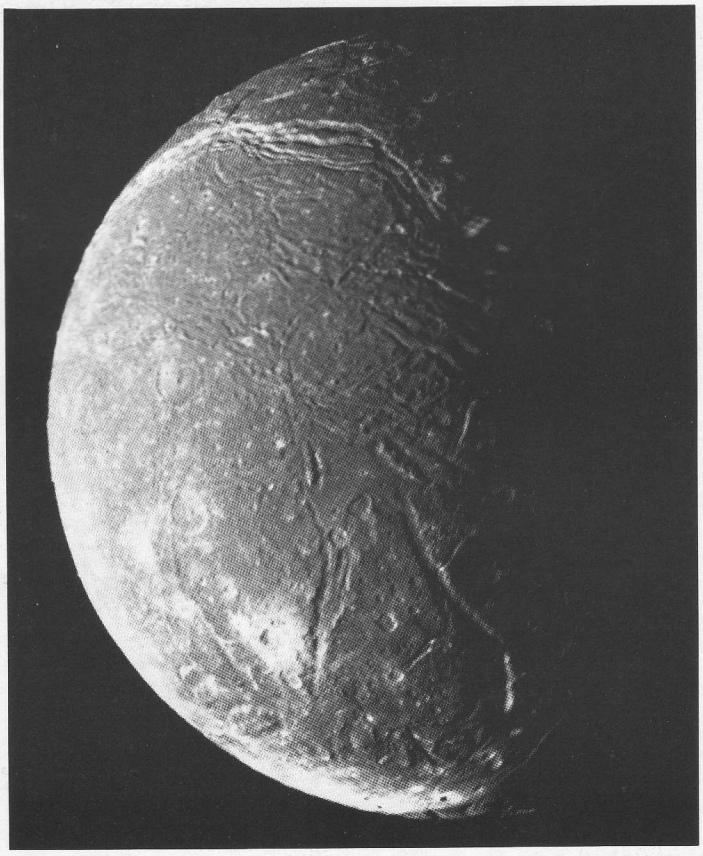
Support of Science Observations

Navigation data is also critical to the success of crucial science observations which depend not only on knowledge of the spacecraft's location, but also on proper, accurate pointing of the instruments aboard Voyager's steerable platform. During the Uranus encounter, the entire spacecraft itself was rotated at precisely determined rates to provide a camera panning motion that reduced image smear. This technique – target motion compensation – supported eight separate sets of imaging observations. For example, the best resolution of the satellite Miranda was obtained in an eight-frame mosaic taken as the spacecraft, sweeping past Miranda at 70,000 kilometers per hour, rotated to track the tiny satellite.

Also, since the exact time of arrival could not be determined early enough to make changes in the flight path, an 8-hour segment of science observations near closest approach was designed in a movable block of instructions to the spacecraft. The entire block could be shifted by up to ± 12 minutes in 48-second increments, while within the block, critical radio science observations could be shifted by ± 72 seconds in 1-second increments. This design allowed the timing of the observations to be shifted without expending fuel to change the time of flight. The instructions that modified the timing of the movable block were sent to the spacecraft on January 24 as an overlay to a sequence already in progress. As it turned out, the navigation data was so accurate that the movable block needed to be shifted by only -48 seconds.



Abundant impact craters of many sizes pockmark the ancient surface of Titania, the largest satellite of Uranus with a diameter of a little more than 1,600 kilometers (1,000 miles). The most prominent features are fault valleys that stretch to 1,500 km (nearly 1,000 mi) long and as much as 75 km (45 mi) wide. In valleys seen at right-center, the sunward-facing walls are very bright. While this is due partly to the lighting angle, the brightness also indicates the presence of a lighter material, possibly young frost deposits. An impact crater more than 200 km (125 mi) in diameter distinguishes the very bottom of the disk; the crater is cut by a younger fault valley more than 100 km (60 mi) wide. An even larger impact crater, perhaps 300 km (180 mi) across, is visible at top. This is the highest-resolution picture of Titania returned by Voyager 2. It is a composite of two images taken January 24, 1986, through the clear filter of Voyager's narrow-angle camera. At the time, the spacecraft was 369,000 km (229,000 mi) from the moon; the resolution is 13 km (8 mi).



Much of Ariel's surface is densely pitted with craters 5 to 10 kilometers (3 to 6 miles) across. Numerous valleys and fault scarps crisscross the highly pitted terrain. The valleys may have formed over down-dropped fault blocks (graben); apparently, extensive faulting has occurred as a result of expansion and stretching of Ariel's crust. The largest fault valleys, near the terminator at right, as well as a smooth region near the center of this image, have been partially filled with deposits that are younger and less heavily cratered than the pitted terrain. Narrow, somewhat sinuous scarps and valleys have been formed, in turn, in these young deposits. It is not yet clear whether these sinuous features have been formed by faulting or by the flow of fluids. Ariel is about 1,200 km (750 mi) in diameter; the resolution here is 2.4 km (1.5 mi). This is a mosaic of the four highest-resolution images of Ariel, taken through the clear filter of Voyager's narrow-angle camera on January 24, 1986, at a distance of about 130,000 km (80,000 mi).

NASA

National Aeronautics and
Space Administration

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JPL 410-15-77 2/86

Status Bulletin Editor: Anita Sohus ..... (818) 354-4438
Public Information Office ..... (818) 354-5011
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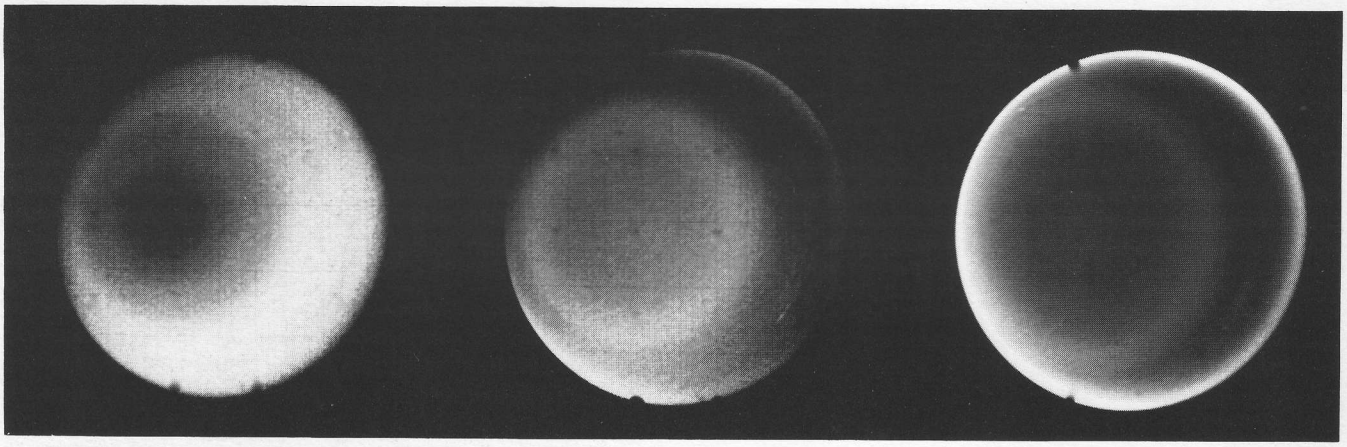
Voyager Bulletin

MISSION STATUS REPORT NO. 78 FEBRUARY 10, 1986



This trio of Voyager 2 images of Uranus shows the varying appearance of the planet as photographed through different color filters of the spacecraft's wide-angle camera. The images were taken January 23, 1986, through the violet, orange and methane filters (displayed in that order, from left). Voyager was 2.1 million kilometers (1.3 million miles) from Uranus; the resolution was 300 km (190 mi). The special properties of the methane filter permit views of the planet in light at a wavelength (0.619 micrometers) that can be strongly absorbed by atmospheric methane. Areas that appear bright in the methane image are generally ones of high clouds, in which the light-scattering particles lie above the methane gas. The discrete bright clouds seen in the methane image (upper left of disk) are probably convective regions where particles have been carried upward above the absorbing methane gas. The dark band at the same latitude is a deeper cloud that lies within the absorbing methane. The region near the very edge of the planet appears bright in the methane image, because the oblique viewing geometry concentrates light scattered from haze at high altitudes, where methane gas is absent. The polar region is one of high haze particles that are dark in violet (left image) relative to the gas molecules. The discrete clouds seen in the orange image (center) and methane image are probably buoyant features of the methane cloud layer that rise to somewhat higher altitudes than the main cloud mass. In violet light, the overlying atmosphere is too opaque to permit these clouds to be seen as easily as in the other filtered images. The darker areas at higher latitudes seen in the violet image may be due to a larger amount of absorbing haze particles in these locations.

"We're happily bewildered," says Voyager Project Scientist Edward Stone of the California Institute of Technology, describing the aftermath of Voyager 2's mad dash through the Uranian system in late January. "We'd be disappointed if we weren't: if it's not bewildering, you haven't learned much!"

Voyager 2 revealed the first planet unknown to the ancients, the first planet discovered by a man we can name, and brought it and its family of moons and rings into our living rooms with startling clarity. For most of us, even the youngest, this will be the only closeup view of Uranus in our lifetime. And we stand with the tired, happy scientists, marvelling at the bizarre surface of Miranda; the cold blue mystery of the planet's atmosphere; the sheet of diverse, enigmatic rings; multiple small dark moons; and a magnetic field that contorts in the solar wind like a double helix. All these were unknown to ancient man, and until a few weeks ago, to modern man as well. This is what it means to be on the cutting edge.

All this brought to us by a one-ton spacecraft designed twelve or more years ago, launched eight-and-a-half years ago, built by thousands, now operated by hundreds.

It is humbling to think that all this can be accomplished with very small onboard computing power. The amount of memory in each of the spacecraft's onboard computers is surpassed by most of today's personal computers. Voyager has three onboard computers, each with two processors. Of course, a large ground support system at JPL, the Deep Space Communications Complexes, and the home institutions of the principal investigators comprise much more computing power for processing and analyzing the data once it is returned to Earth.

The spacecraft's attitude and articulation control subsystem (AACS) and computer command subsystem (CCS) each have two 4-K (18-bit words) plated wire memories, while the flight data subsystem (FDS) consists of two 8-K (16-bit words) semiconductor memories.

Usually, the contents of one computer subsystem's processors are redundant, to safeguard against loss of one processor. The CCS processors operate in parallel, using about 3 K per machine for spacecraft housekeeping and failure protection and only about 1 K per machine (2 K total) for the sequences that direct the spacecraft (and its other two computers) to observe the planets.

During the Uranus mission, some redundancy was given up to reconfigure the second of the two FDS processors to compress image data, allowing transmission of the same amount of information using less than half the number

of bits. This was done by transmitting the brightness of the first pixel in each line of an imaged scene, and then transmitting only the relative difference between adjacent pixels in the remainder of the line. Each image contains 640,000 pixels. Previously, each pixel required 8 bits to describe it and its gray level from 0 to 255. The image data compression technique reduced this requirement to about 3 bits per pixel, cutting the bits per image from 5.12 million to less than 2 million.

The Planet

Almost nothing was known about Uranus before the Voyager encounter, in comparison with knowledge about other planets in our solar system. It lies on its side, its rotational axis lying 8° below the plane of the ecliptic (the plane in which most of the Sun's planets and satellites orbit). It completes an orbit about the Sun every 84 years, exposing its north and south hemispheres to the Sun or to cold deep space for periods as long as 42 years at a time.

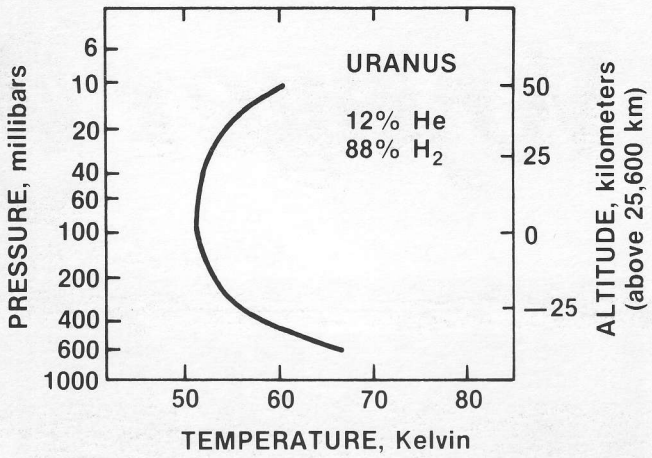
The Earth-orbiting International Ultraviolet Explorer (IUE) spacecraft detected ultraviolet (UV) emissions from the planet, indicating that it might have a magnetic field. (Ultraviolet light is emitted when charged particles spiral into a planet's atmosphere along its magnetic field lines. This phenomenon has been observed at Earth, Jupiter, and Saturn.) The character of a planet's magnetic field gives scientists clues to the planet's interior composition.

Models for the planet's interior supposed a small rocky core about the size of Earth, a deep ocean of water, methane, and ammonia about 10,500 kilometers (6,500 miles) thick, and a dense atmosphere of molecular hydrogen 7,600 kilometers (4,700 miles) thick. Before the Voyager flyby, ground-based observations of Uranus led some theorists to propose that the helium abundance (the ratio of hydrogen to helium) might be as high as 40 percent—way out of scale in comparison to the helium abundance of Jupiter (11 percent) and Saturn (7 percent). Helium abundance is a clue to the early evolution of the planetary nebula and the formation of planets. To first order, all planets should have about the same helium abundance as the Sun. The low abundance on Saturn is due to the precipitation of helium to the interior.

Voyager proved that Uranus does indeed have a quite a large and unusual magnetic field, that its dark pole is surprisingly slightly warmer than its sunlit pole, that its rotation rate is about 17 hours, and that its helium abundance is only about 12 percent, with an uncertainty of 4 percent.

Winds on Uranus blow in the same direction as the planet rotates (opposite to the case on Earth), and at speeds of 15 to 220 meters per second (as compared to Earth's 100 meter per second jet streams 9 kilometers above the Earth's surface).

The average temperature on Uranus is 60 kelvins (K)—a chilling −350° F. The minimum near the tropopause—



The atmosphere of Uranus appears to be about 12 percent helium and 88 percent hydrogen, based on temperature and pressure profiles compiled by radio science data and infrared spectrometry data and compared to theoretical models. This profile was compiled from data acquired as Voyager 2 disappeared behind the planet as seen from Earth, and its radio signal was refracted (bent) by the planet's atmosphere. This refractivity depends on the density and constitutents of the gases in the atmosphere. Radio signals penetrated to about the 2.5 bar pressure level. The temperature at the 100 millibar level (25,600 kilometers from the center of the planet) is about 52 kelvins.

the boundary between the troposphere (where life abounds on Earth) and the stratosphere—is about 52 K at the one-tenth bar pressure level (the average pressure at sea level on Earth is 1 bar). Between about 15° and 40° latitude, temperatures are 2 to 3 K lower. This band corresponds to a region where cloud streaks have been observed in Voyager images, but what connection there may be between these two observations is still being studied. Temperatures rise above the one-tenth-bar level to as much as 100 K. Below this level, temperatures continue to increase to thousands of kelvins deep in the interior.

A high-altitude haze layer may include polyacetylene hydrocarbons, possibly produced photochemically. The radio observations reached deep into the atmosphere, to where the pressure is greater than 2.5 bars. This is below the level where methane clouds are believed to form. Temperatures in the atmospheres of Jupiter and Saturn are too warm to allow such methane clouds to develop.

Ultraviolet observations of the atmosphere detected a deep atmosphere of molecular hydrogen over a layer of hydrocarbons, including acetylene.

Uranus also has an extended corona of atomic hydrogen, with temperatures approaching 750 K. On the dayside atmosphere, bright emissions from atomic and molecular hydrogen extend thousands of kilometers above the limb and across the sunlit disk. Similar emissions occur at Jupiter and Saturn, and the term "electroglow" has been coined to describe the phenomena. The cause of the UV emissions is suspected to be photoelectrons which are accelerated to high energies by some still unknown mechanism.

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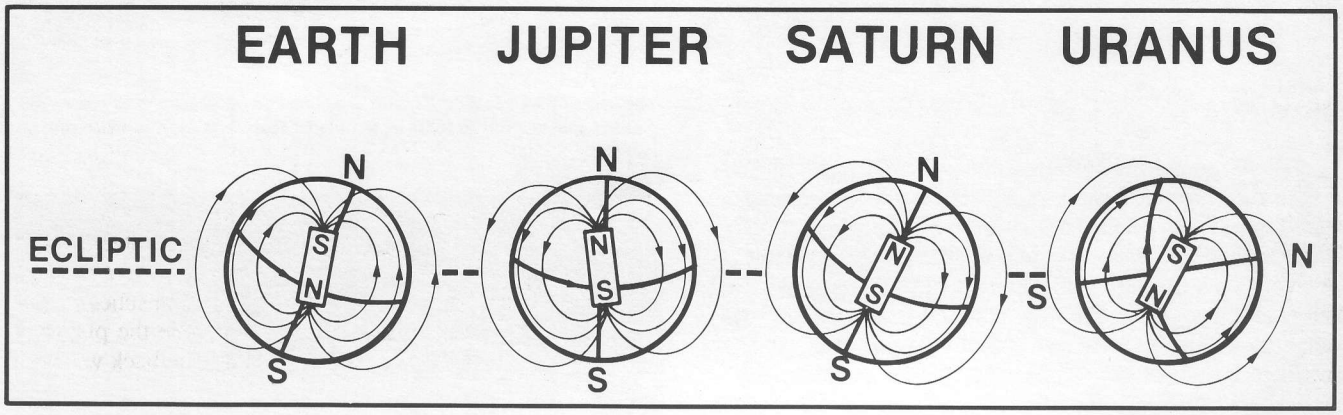
JPL 410-15-78 2/86

Status Bulletin Editor: Anita Sohus ..... (818) 354-4438
Public Information Office ..... (818) 354-5011
Recorded Mission Status ..... (818) 354-3051

Voyager Bulletin

MISSION STATUS REPORT NO. 79 FEBRUARY 12, 1986



A planet's rotational axis is not necessarily perpendicular to the ecliptic plane, the magnetic axis is not necessarily aligned with the rotational axis, and the magnetic poles do not always correspond to the rotational poles. In the case of Uranus, the magnetic axis is inclined 55° below the rotational axis, which is inclined 8° below the ecliptic. In this diagram of Earth, Jupiter, Saturn, and Uranus (not to scale), the rotational axes are shown by straight solid lines bisecting the planets; the magnetic axes are shown by the bar magnets; the ecliptic plane is the dotted line through the center of the diagram; and the direction of rotation and wind flow is shown by the arrowhead on the curved line at each planet's equator. Magnetic field lines extend into space and form a "cage" around a planet, trapping charged particles and sweeping them around in space as the planet rotates.

The Magnetosphere

Voyager 2 discovered that Uranus not only has a magnetosphere, but that it is a very large and wonderful magnetosphere.

One may think of a magnetosphere as a windsock-shaped object surrounding a planet, with its head toward the Sun and its tail streaming behind it in the solar wind. The magnetosphere is formed when energetic particles are trapped within a planet's magnetic field lines. Earth, Jupiter, and Saturn all have substantial magnetospheres—in fact, were it visible, Jupiter's magnetosphere would appear to an observer on Earth to be larger than the full moon. Mercury has a small magnetic field, while Venus and Mars have virtually no magnetic fields. Uranus' magnetic force is about the same as that at Saturn and Earth.

Envisioning a bar magnet in the interior of Uranus, this magnet is tilted 55° below the rotation axis, which is already tilted 8° below the ecliptic plane. In addition, the polarity of this bar magnet is similar to the situation at Jupiter and Saturn and opposite to the situation at Mercury and Earth. (Earth's south magnetic pole is currently near its north rotational pole; there is evidence that the Earth's polarity has reversed many times in the past.)

The combined effect of the extreme tilt of the magnetic axis and the tilt of the rotational axis is that the planet's magnetotail is swept around in space like a corkscrew. Plasma in the tail undergoes magnetic field reversals as the magnetic axis rotates.

The character of a planet's magnetic field can provide clues to the interior of the planet. A magnetosphere indicates that an electrically conducting region within the planet is being mechanically stirred. Uranus' magnetic field is probably generated in electrical currents in its ion-laden ocean layer.

As charged particles are swept around with the rotation of a planet's magnetic field, natural radio signals are created. Radio emissions from Uranus were not detected until January 16, much later than expected. The radio emissions are used to determine the rotation rate of the planet's interior, where the magnetic field is generated.

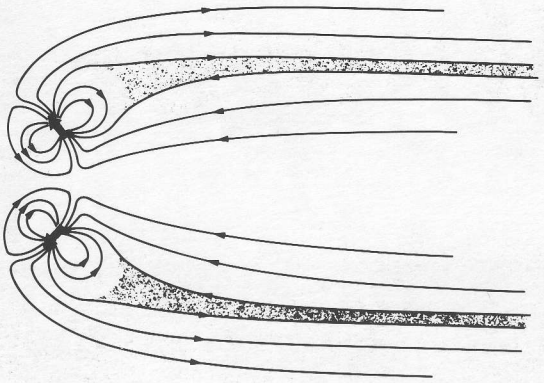
At the boundary of the solar wind and a planetary magnetosphere, a shock wave exists. Voyager 2 experienced the Uranian bow shock over 17,000 kilometers from the planet on January 23, 10-½ hours before closest approach. Three hours later, the spacecraft passed out of the turbulent magnetosheath area and into the magnetosphere proper.

Uranus' rings and the satellites Miranda, Ariel, and Umbriel are within the sunward magnetosphere. As the satellites orbit, they cut a swath through the charged particles in the magnetosphere.

In the outer magnetosphere, the particles are mostly ionized hydrogen, quite different from Earth, Jupiter, and Saturn.

Uranus also possesses radiation belts similar in intensity to Earth's Van Allen radiation belts. The darkness of the satellites and rings may be a result of radiative separation of hydrogen and carbon from the methane ice on their surfaces.

The temperature of the hot plasma of the radiation belts exceeds 500 million degrees, yet the density is so low that exposed flesh would freeze instantly.



The large offset between Uranus' rotational and magnetic axes causes the planet's magnetotail to twist as the planet rotates as seen in these mirror images.

The Rings

The Uranian ring system seems to be distinctly different than the rings of Jupiter or Saturn. Radio observations showed that the Uranian rings seem to be composed mostly of boulder-sized particles, greater than 1 meter in diameter. However, a very tenuous distribution of fine dust seems to be spread throughout the ring plane. Such dust may be formed by collisions between larger ring particles, and is thought to be swept out of the ring system in some way.

The rings also vary slightly in color, indicating slightly differing composition in different rings.

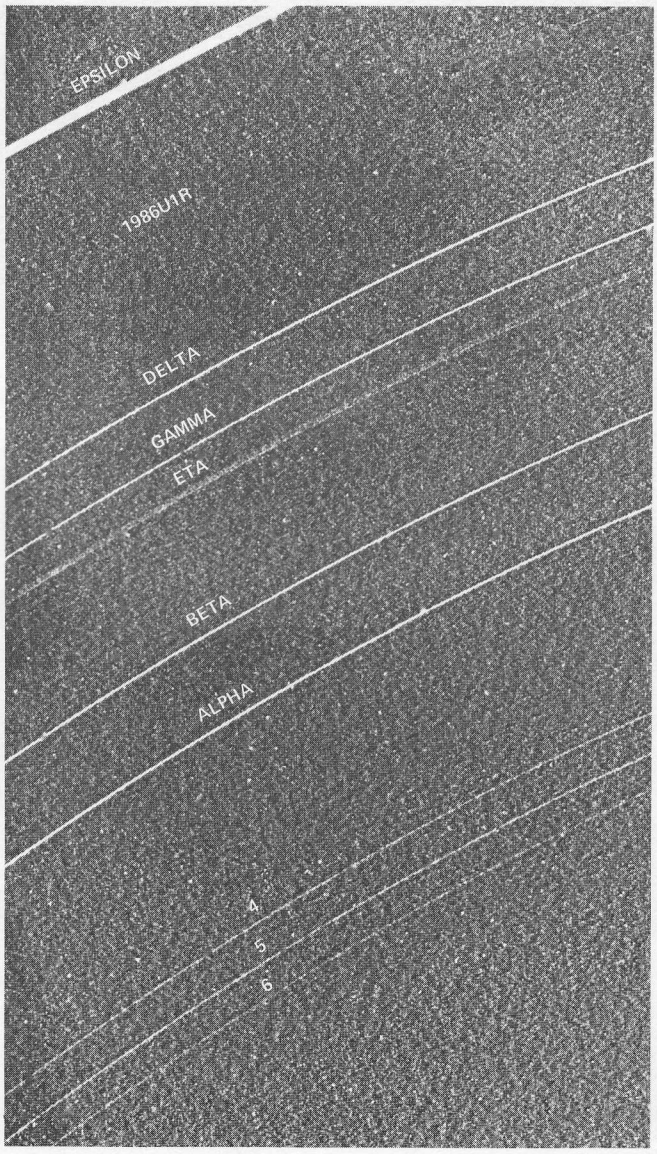
While no braided rings were found, there may be a number of very narrow or even incomplete rings (arcs). The mechanism for these is unknown.

The discovery of two tiny satellites flanking the epsilon ring strengthened the theory of "shepherding moons" developed from observations at Saturn. Such moons appear to be the mechanism that keeps ring material orbiting a planet rather than escaping into space.

Other small satellites were expected to be seen in the rings, but the data are still being analyzed.

As Voyager 2 crossed the plane of the rings (but far outside the rings themselves) the plasma wave instrument detected a large number of dust impacts on the spacecraft. This diffuse dust cloud or ring may be several thousand kilometers thick. Voyager 2 crossed the ring plane about 115,000 kilometers from the center of the planet, inside the orbit of Miranda.

Mountains of data remain to be analyzed. The photopolarimeter, for example, returned 1.5 million discrete measurements as it watched starlight stream through the rings, while the radio experimenters obtained 5 billion measurements which have to be shuffled 1 million times in 1 million steps to account for diffraction of the radio signal.



Voyager 2 1/23/86 1.12 million km (690,000 mi.)

NASA
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California
JPL 410-15-79 2/86

Status Bulletin Editor: Anita Sohus ..... (818) 354-4438
Public Information Office ..... (818) 354-5011
Recorded Mission Status ..... (818) 354-3051

Voyager Bulletin

MISSION STATUS REPORT NO. 80 FEBRUARY 25, 1986

Satellites of Uranus

Uranus' five largest satellites — Miranda, Ariel, Umbriel, Titania, and Oberon — were discovered over a period of 161 years from 1787 to 1948. Until the Voyager flyby they were no more than points of light in even the best Earth-based telescopes.

All of the best resolution observations of the Uranian satellites occurred within an 8-hour span, due to the unique tilted orientation of the planet and satellite orbits. Because so much was happening in such a short period, many of the observations were recorded on the spacecraft's digital tape recorder and played back to Earth later.

At the press conference on January 26, imaging team member Larry Soderblom, of the U.S. Geological Survey, told the media, "No one could have anticipated the exotic things I'm going to show you this morning.

"As we move closer to Uranus, we see increasing ferocity in the way these bodies have been tectonically shuffled in cataclysmic fashion, and it doesn't seem to be related to time," said Soderblom. "Sandwiched between some very active objects is an object that is very dark and inactive (Umbriel). We don't know why."

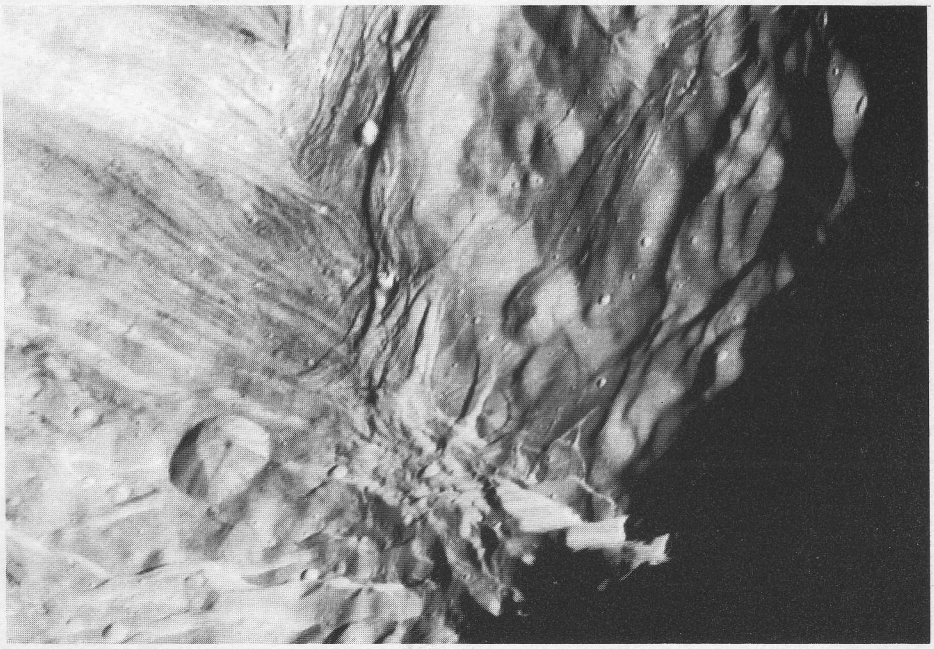
Umbriel is an enigma in the solar system because it is so gray and bland. It orbits between two pairs of satellites that show much geologic history, yet it itself is dark and shows little contrast. It may be the oldest satellite surface in the Uranian system. A white donut-shaped patch near the north pole is 30 percent brighter than most of Umbriel and may be material in the floor of a 150-km diameter crater. Umbriel also has several overlapping large craters, with diameters from 100 to 200 km.

Oberon has many craters, which probably formed more recently than the period of meteoroid bombardment throughout the solar system nearly 2.5 million years ago. Material in the crater floors looks as though it were deposited sometime even later than the crater formation. Oberon also has a large mountain, rising nearly 6 km (4 mi) above the surface.

Internal processes must be at work on Titania, where bright frost-like material appears to be leaking out of the interior through graben-like features caused by crustal faulting.

Ariel, the brightest of the large moons, shows evidence of a great deal of geologic activity in the past. Fracture patterns, deep incisions into the surface, may be tensional fault systems. These valley floors appear to be filled by a single continuous flow of material. Other valleys are more sinuous and may have been caused by fluid flow or sublimation. One image shows three linear features, which look remarkably like the flow of an ice mass, such as a glacier on Earth. Any such process must have occurred some time ago, however, since the large numbers of craters overlying this feature indicate that it is quite old.

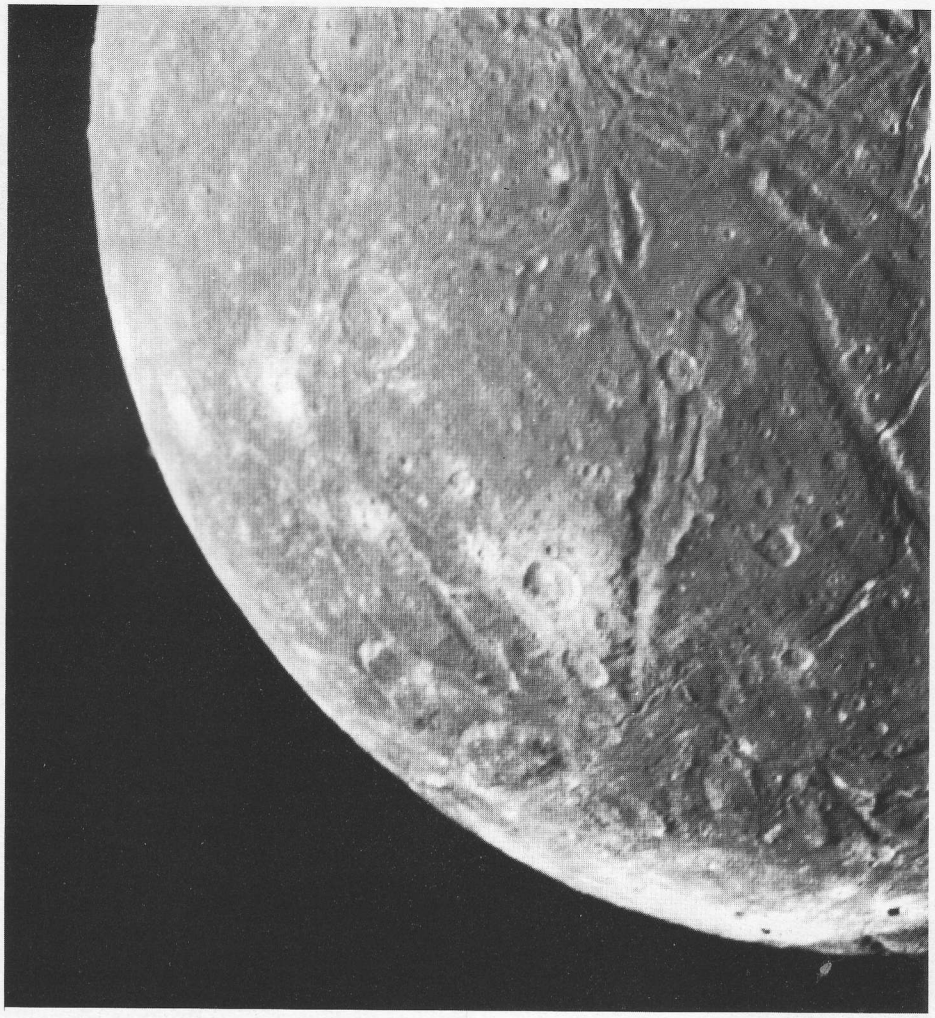
Miranda

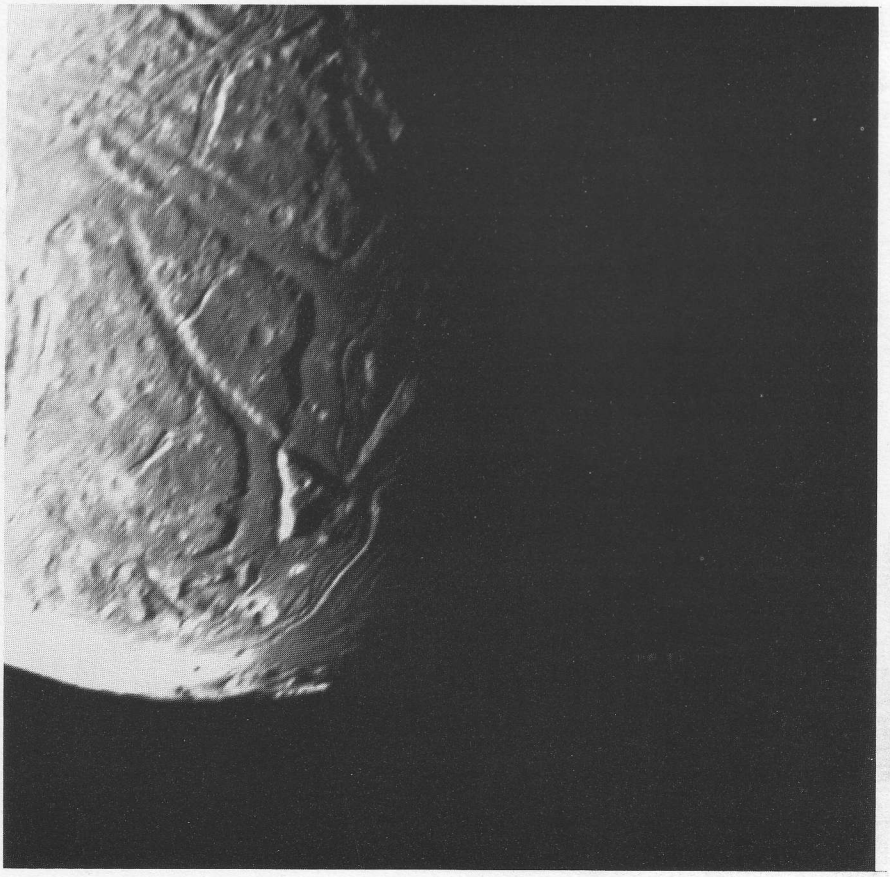


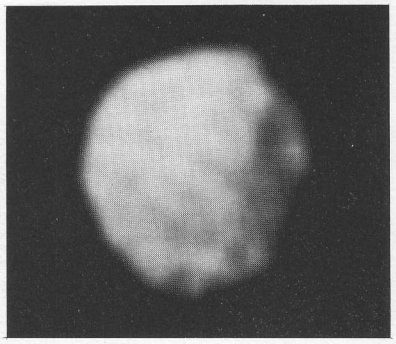
Sunlight reflects dramatically from cliff faces which drop abruptly from higher, older, cratered terrain to lower, striated elevations on Miranda. The precipice may be 5 km (3 mi) deep. Sinuous scarps, probably caused by faulting rather than erosion, cut across both terrains. The impact crater at lower center in this image is about 25 km (15 mi) across. This clear-filter, narrow-angle image shows an area about 250 km (150 mi) across, at a resolution of about 800 meters (2,600 feet) and was taken January 24, 1986 from 36,000 km (22,000 mi).

Ariel

The complexity of Ariel's surface indicates that a variety of geologic processes have occurred. The numerous craters, for example, are indications of an old surface bombarded by meteoroids over a long period. Also conspicuous at this resolution, about 2.4 km (1.5 mi), are linear grooves (evidence of tectonic activity that has broken up the surface) and smooth patches (indicative of deposition of material). Below, the highest-resolution view of Ariel's terminator shows a complex array of transecting valleys with superimposed impact craters. Particularly striking is the fact that the faults that bound the linear valleys are not visible where they transect one another across the valleys. Apparently these valleys were filled with deposits sometime after they were formed by tectonic processes, leaving them flat and smooth. Sinuous rilles (trenches) later formed, probably by some flow process. Some type of fluid flow may well have been involved in their evolution. These clear-filter, narrow-angle images were taken on January 24, 1986, from a distance of 130,000 km (80,000 mi).

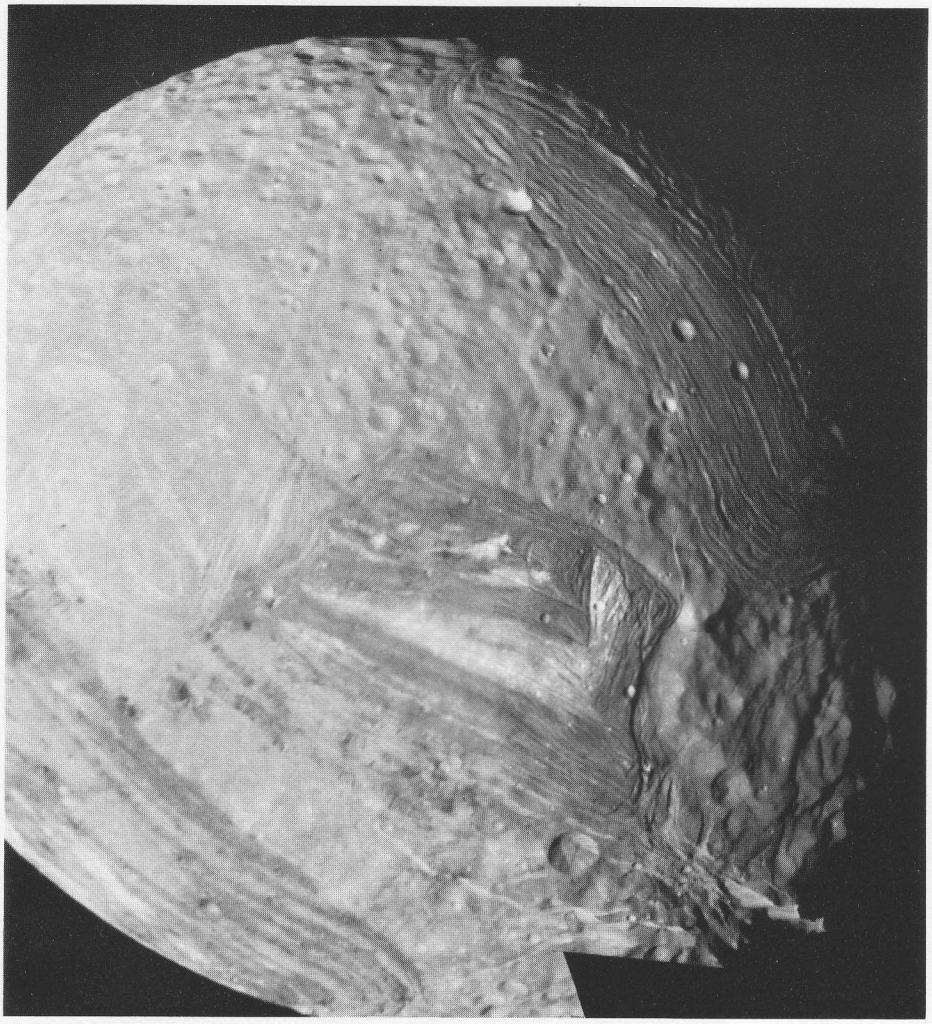




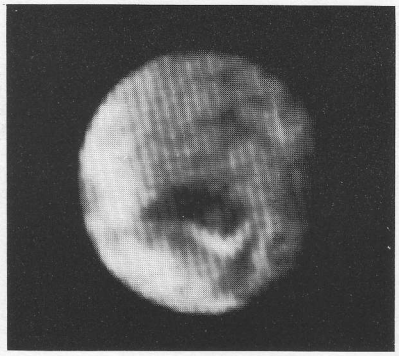


1985U1

Several craters are seen on the surface of 1985U1, one of several small moons of Uranus discovered by Voyager 2. With a diameter of about 150 km (90 mi), 1985U1 appears as a dark, nearly spherical object; the dark surface reflects only 7 percent of the incident light. The spacecraft acquired this single image—the only close-up it obtained of any of the new moons—on January 24, 1986. At the time, Voyager was about 500,000 km (300,000 mi) from 1985U1, yielding a resolution of about 10 km (6 mi) in this clear-filter, narrow-angle image.



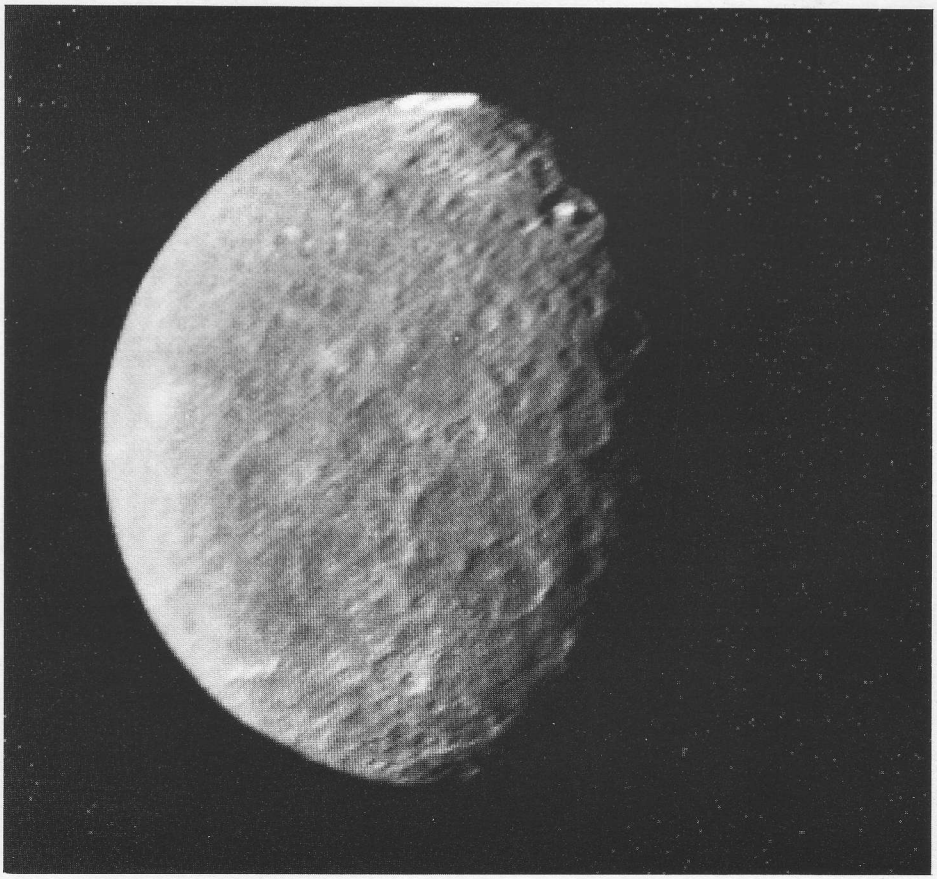
Miranda



Miranda, roughly 500 km (300 mi) in diameter, exhibits varied geologic provinces, seen in this computer-assembled mosaic (left) of images taken January 24, 1986. The images were obtained from distances of 30,160 to 40,310 km (18,730 to 25,030 mi); resolution ranges from 560 to 740 meters (1,840 to 2,430 feet). Without the target motion compensation technique devised by this Voyager flight team, the top image, with a resolution of about 26 km (16 mi), would have been the best resolution obtained at Miranda. This technique allows the spacecraft to drift at a controlled rate to track the target body and reduce image smear caused by high relative velocities between the spacecraft and the target. These are among the highest-resolution pictures that Voyager has obtained of any of the new "worlds" it has encountered during its mission. The missing piece of Miranda's surface will be included in a later mosaic once more complicated computer processing can be completed.

Umbriel

Umbriel is the darkest of Uranus' larger moons and the one that appears to have experienced the lowest level of geological activity. The southern hemisphere of the moon displays heavy cratering. Umbriel has a diameter of about 1,200 km (750 mi) and reflects only 16 percent of the light striking its surface; in the latter respect, it is similar to lunar highland areas. Umbriel is heavily cratered but lacks the numerous bright-ray craters seen on the other large Uranian satellites; this results in a relatively uniform surface albedo (reflectivity). The prominent crater on the terminator (the day-night boundary, right) is about 110 km (70 mi) across and has a bright central peak. The strangest feature in this image is a curious bright ring (at top), the most reflective area seen on Umbriel. The ring is about 140 km (90 mi) in diameter and lies near the satellite's equator. The nature of the ring is not known, although it might be a frost deposit, perhaps associated with an impact crater. Spots against the black background are due to "noise" in the data. Voyager 2 took this image on January 24, 1986, from a distance of 557,000 km (346,000 mi). This frame, taken through the clear filter of Voyager's narrow-angle camera, is the most detailed image of Umbriel, with a resolution of about 10 km (6 mi).



	RING WIDTH (km)	BODY DIA. (km)	ORBITAL DISTANCE (km)
URANUS		25,600	
1986U2R	3000		39,000
RING 6	1		41,877
RING 5	1		42,275
RING 4	1		42,610
alpha	8		44,758
beta	8		45,701
eta	1		47,215
gamma	2		47,666
delta	6		48,339
1986U7		30	49,300
1986U1R	3		50,000
epsilon	58		51,188
1986U8		20	53,300
1986U9		60	59,100
1986U3		70	61,750
1986U6		50	62,700
1986U2		70	64,350
1986U1		90	66,090
1986U4		50	69,920
1986U5		50	75,100
1985U1		170	85,982
Miranda		480	129,783
Ariel		1170	191,239
Umbriel		1190	265,969
Titania		1590	435,844
Oberon		1550	582,596

Miranda, smallest and innermost of the large satellites, is the most bizarre, with scarps, sawtooth terraces, extensional and compressional faults, cratering, slabs, and trenches. Planetary geologists studying Miranda's geomorphology — geologic shapes — plan to use Voyager images to construct three-dimensional models of Miranda using stereogrammetry. Most of the terraces are on the Uranus-facing hemisphere. Miranda is a slightly warm object with a reddish cast. Different colors may indicate different materials or processes.

Dr. Soderblom presented a possible model for Miranda's evolution, in which loose material accreted, differentiated, fragmented, and then reaccreted. He also suggested that the chevron, "racetrack"-like features, and open trenches are all steps in the evolution of features on Miranda's surface.

Early analysis suggests that the darkness of the satellites' surfaces may be caused by radiative damage from Uranus' radiation belts, where ions impacting methane ice on the surface breaks the ice into hydrogen and carbon and the hydrogen is driven off into space by fast protons, leaving the dark carbon behind. Cosmic ray investigators have calculated that in 100 years, 100 trillion protons would hit the satellite surfaces, leaving a dark residue.

As anticipated, Voyager 2 discovered many small satellites in and near the rings of Uranus, but no new large objects were found.

Between December 30 and January 23, ten new moons were discovered in Voyager data. These range in diameter from 20 to 170 kilometers and are very dark. Because they are so small, little more can be determined about them aside from their sizes, orbital distances, and orbital periods.

The largest of these, 1985U1, is remarkably round and has at least two craters. 1985U1 was resolved in a single Voyager image that was inserted into the observational sequences soon after the satellite was discovered at the end of December. Receipt of the image itself was a "cliffhanger" since the original playback was lost due to a few minutes of mechanical problems at the tracking station scheduled to receive it. Engineers were able to reschedule the playback without loss of other data, and the second playback was successfully received.

Two of the small satellites, 1986U7 and 1986U8, flank the epsilon ring. They are called "shepherding satellites" because they are thought to herd ring particles between them, keeping the particles in orbit around Uranus (otherwise the ring particles might escape to space or fall into the planet). Shepherding satellites were first discovered in the rings of Saturn.

The photopolarimeter experiment may have detected other small satellites in the rings. Satellites within a ring system tend to clear a path, much like the wake of a boat. Such wakes appear in the data of the photopolarimeter instrument, which measured structures in the ring system as small as a few meters across.

February 25 marks the end of the Uranus encounter period. The official summaries of the Uranus findings will be published in *Science* magazine in late May 1986.

Voyager 2 is on its way to Neptune, which it will encounter on August 25, 1989 (Universal Time) at a distance of barely 1300 kilometers (800 miles) above its cloudtops.

Neptune is about the same size as Uranus. It has an internal heat source, so the convective actions in its atmosphere should be more conducive to observing cloud features. In addition, Voyager 2 will fly about 6000 kilometers (2000 miles) from Triton, Neptune's largest satellite (slightly larger than Jupiter's Io). These dual encounters (Neptune and Triton) will be Voyager's closest flybys since launch from Earth. Triton's orbit is retrograde — in the opposite direction to most planetary motions. Triton appears to have a methane atmosphere, with liquid nitrogen on its surface.

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JPL 410-15-80 2/86

Status Bulletin Editor: Anita Sohus ..... (818) 354-4438
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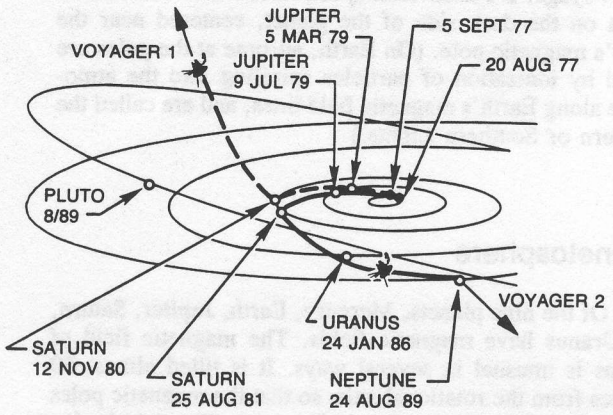
Voyager Bulletin

MISSION STATUS REPORT NO. 81 MARCH 21, 1988



Introduction

In 1977, two one-ton spacecraft were launched toward Jupiter and Saturn on a journey of exploration. Today, 10-½ years after their launch, the Voyager spacecraft continue to expand our knowledge of the solar system.

This issue of the Voyager Bulletin summarizes Voyager 2's findings at Uranus in January 1986. Future issues will focus on preparations for the Neptune encounter in the summer of 1989, including the health of the spacecraft, science objectives for the encounter, and the Voyager flight team organization.

Uranus

The seventh planet from the Sun, Uranus, was discovered in 1781 by astronomer and musician William Herschel from the backyard of his home in Bath, England. Herschel called it the Georgian Star, after King George III. Astronomers provisionally called the planet Herschel, but it became known as Uranus, after the father of Saturn in Greek mythology.

Over the next 200 years, scientists could gather only the sketchiest of information about Uranus. They knew that it orbits the Sun at about 19 AU*, and that light takes 2 hours and 45 minutes to travel between Uranus and Earth. They knew that Uranus orbits the Sun once in 84 years, resulting in seasons that are about 21 years long at any particular spot on the planet, as different hemispheres face the Sun.

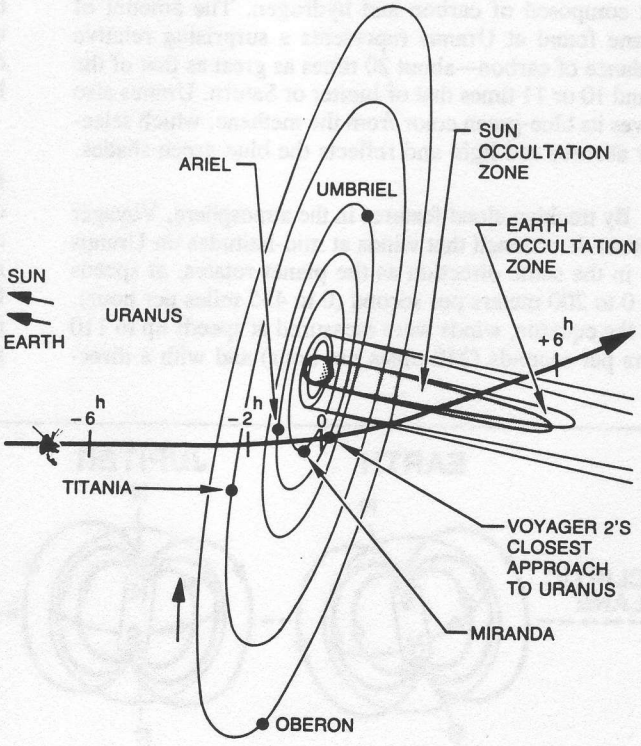
They estimated the diameter of Uranus to be about four times that of Earth, and the mass to be 14 to 17 times that of Earth. They knew that Uranus, like the other giant planets, Jupiter, Saturn, and Neptune, is composed primarily of hydrogen and helium.

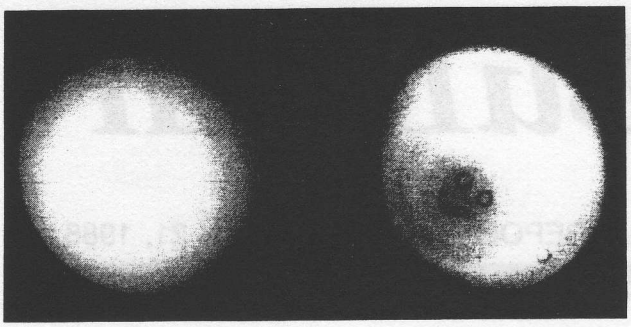
*One astronomical unit is the mean distance between Earth and the Sun, 150,000,000 kilometers (93,000,000 miles).

They also knew that perhaps the most unusual characteristic of the Uranian system is that it lies on its side—the planet's rotational axis is tilted below the plane of the ecliptic. Scientists believe a catastrophic collision with another large body may have been the cause for Uranus' strange tilt.

While each of its poles is effectively in sunlight and the other in complete darkness for 42 years at a time, scientists expected the pole that currently faces deep space to be essentially the same temperature as the pole facing the Sun, and they expected the equator to be a few degrees colder than the poles since it receives less light during a Uranian year than either of the poles. Surprisingly, Voyager 2 found that the atmospheric temperature—about −209°C (−344°F)—varies little from pole to equator to pole, indicating that heat received near the poles must be redistributed toward the equator. On Earth, heat received at the equator is redistributed toward the poles.

The other giant planets all give off about twice as much heat as they receive from the Sun, indicating that heat is generated in their interiors. Uranus, on the other hand, generates no more than about 12 percent more heat than it receives from the Sun.





As seen by human eyes (left), Uranus appears bland and featureless. By enhancing the color and contrast (right), scientists discovered a dark polar hood at the south pole.

Uranus is considerably larger than Earth (63 Earths would fit into the interior of Uranus), yet Uranus spins much faster on its axis—once every 17.24 hours. Using knowledge of a planet's rotation period, the composition of its atmosphere, and its gravity, scientists can estimate the distribution of its internal mass. Before Voyager 2's flyby, scientists believed that Uranus had a rocky core about the size of three Earths, overlain by an "ocean" of ice and a layer of molecular hydrogen. However, the planet's rotation period indicates that the heavier materials are not so centrally located. Scientists now believe that Uranus may have an interior in which rocky material, ammonia, water, and methane are almost uniformly mixed with hydrogen and helium. This uniform, dense fluid is extremely hot—10,500°C (18,900°F)—and under great pressure so that it is highly electrically conductive and gives rise to Uranus' magnetic field.

The outer atmosphere is about 16 percent helium and 83 percent hydrogen, which is very similar to the composition of the Sun. Uranus also has a large amount of methane, a gas composed of carbon and hydrogen. The amount of methane found at Uranus represents a surprising relative abundance of carbon—about 20 times as great as that of the Sun and 10 or 11 times that of Jupiter or Saturn. Uranus also receives its blue-green color from the methane, which selectively absorbs red light and reflects the blue-green shades.

By tracking cloud features in the atmosphere, Voyager scientists determined that winds at mid-latitudes on Uranus blow in the same direction as the planet rotates, at speeds from 0 to 200 meters per second (0 to 435 miles per hour). Near the equator, winds were measured at speeds up to 110 meters per seconds (240 miles per hour) and with a direction opposite that of planetary rotation . [On Earth, jet streams blow at about 50 meters per second (110 miles per hour) 9 kilometers above Earth's surface.]

Uranus also has an extended atmosphere composed mostly of neutral (un-ionized) hydrogen. This atmosphere, stretching about 6,000 kilometers (3,700 miles) above the cloudtops, can be seen only in ultraviolet light. When sunlight strikes it, the extended atmosphere glows, a phenomenon called "dayglow".

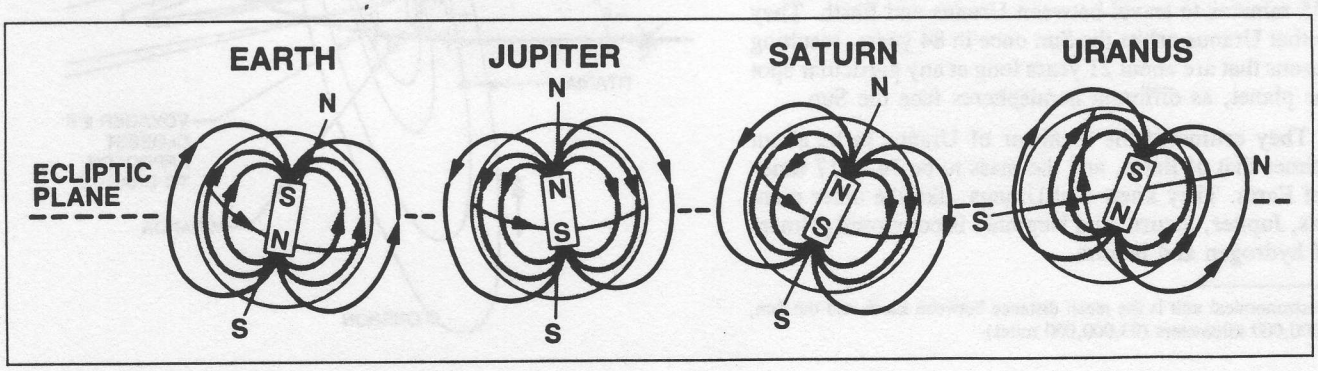
Voyager 2's ultraviolet spectrometer also detected an aurora on the dark side of the planet, centered near the planet's magnetic pole. (On Earth, aurorae at the poles are caused by ionization of particles spiraling into the atmosphere along Earth's magnetic field lines, and are called the Northern or Southern Lights.)

Magnetosphere

Of the nine planets, Mercury, Earth, Jupiter, Saturn, and Uranus have magnetic fields. The magnetic field of Uranus is unusual in several ways. It is tilted almost 60 degrees from the rotational axis, so that the magnetic poles are closer to the equator than to the poles. The field is also offset from the center of the planet by about one-third of the planet's radius. Neither of these phenomena have been adequately explained. Some scientists speculate that Uranus may be undergoing a magnetic field reversal (there is geologic evidence for numerous field reversals on Earth). Or, it may be that the dynamo region from which the field arises is just closer to the surface on Uranus than at other planets.

The magnetic field of a planet extends some distance into space, encircling the planet in a "cage" (the "magnetosphere") that captures charged particles and rotates with the planet. All of Uranus' rings and satellites are within its magnetosphere, which extends to about 590,000 kilometers on the sunward side of the planet and to about six million kilometers on the night side.

When the solar wind (a stream of charged particles from the Sun) meets a planet's magnetic field, the field is compressed on the sunward-side of the planet and drawn into a long "magnetotail" behind the planet as the solar wind rushes past. (One might envision a windsock as an analogy for the shape.) Due to Uranus' tilt on its axis and its offset magnetic field, the rotation of the magnetosphere with the planet imparts a corkscrew twist to the magnetotail.



Within the Uranian magnetosphere there are positively charged particles including a large number of protons. The source of the protons may be the extended hydrogen atmosphere, the ionosphere, or the solar wind. High energy protons (28,000 electronvolts) may be absorbed by methane in the satellite surfaces, freeing hydrogen and leaving a dark, carbon residue on the satellites.

Rings

Nine dark, narrow rings were discovered at Uranus in 1977 from a NASA research aircraft flying above the Indian Ocean. Scientists onboard the plane noticed that the light of a star blinked on and off as they watched Uranus pass in front of the star, and the blinking pattern repeated itself as the star emerged from behind the planet. These rings are known (in order of increasing distance from the planet) as 6, 5, 4, alpha, beta, eta, gamma, delta, and epsilon. Voyager 2 discovered two new rings, for a total of 11. Other ring structures composed of dust-sized particles exist between the classical rings.

Uranus' rings probably did not form at the same time as the planet. They are not all circular, nor are they all precisely in the plane of Uranus' equator as we have come to expect. They range in width from 2 to 100 kilometers, in comparison to Saturn's rings, which span 60,000 kilometers (37,000 miles). Some of them broaden and then narrow, and some are incomplete. They are some of the darkest objects ever studied, as the ring particles reflect only about 5 percent of the sunlight shining on them. (In contrast, Saturn's ring particles are made of water ice and reflect nearly all sunlight.)

The narrowness of the Uranian rings may be due to gravitational interactions with nearby satellites. As orbiting ring particles tend to try either to escape to space or to fall inward toward the planet, scientists believe they are "shepherded" back into their orbits by small satellites. Two such "shepherding" satellites, Cordelia and Ophelia, flank the epsilon ring, but other such satellites were not found because they are probably too small or too dark to have been detected by Voyager 2.

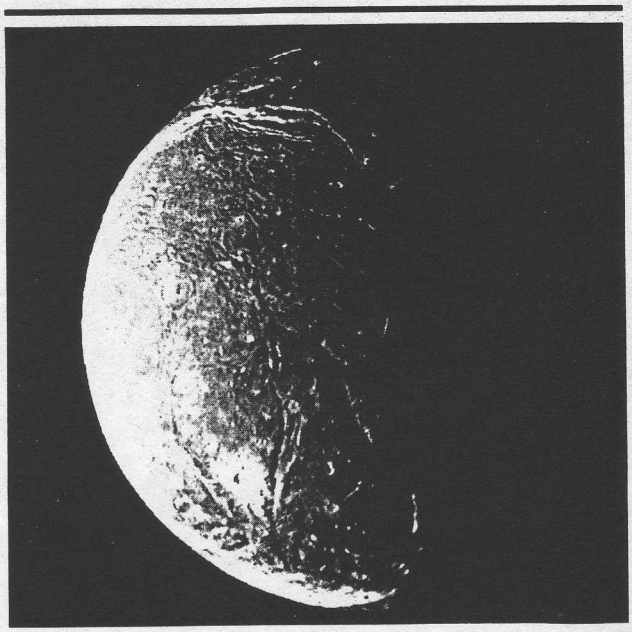
The particles in the previously known rings range in size between baseballs and automobiles, and there is a surprising lack of dust in the main rings. Particles in the newly discovered rings are much smaller, like dust particles.

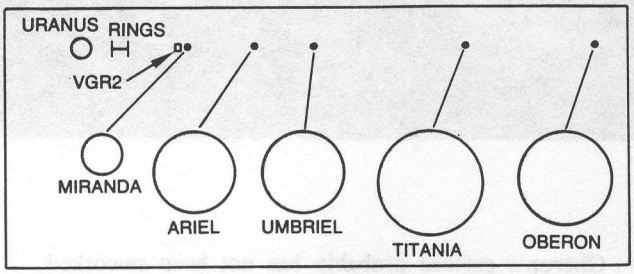
Satellites

Uranus has at least 15 satellites, ten of them discovered by Voyager 2. They all orbit near the plane of the planet's equator, and thus their orbits are nearly perpendicular to the plane of the ecliptic. The Uranian system presented a bull's-eye target for Voyager 2, and thus only the sunlit southern hemispheres of the satellites were imaged.

One would expect to find more ice as one moves away from the Sun, but the larger Uranian satellites may be composed of 50 to 60 percent rocky matter, in contrast to Saturn's more icy satellites. They are also dark, and most scientists agree that the darkness must be caused by carbon-rich surfaces.

Ariel

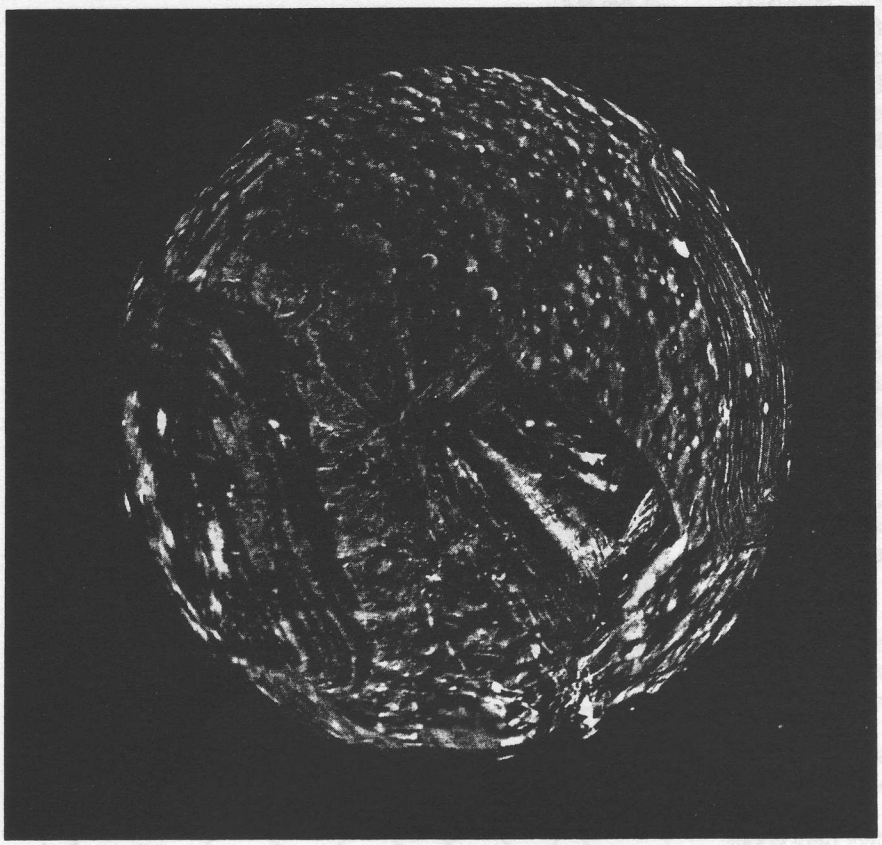




Uranus Bodies

	RING WIDTH (km)	BODY RADIUS (km)	ORBITAL DISTANCE* (km)
URANUS		25,600	
1986U2R	2,500		38,500
RING 6	1 to 3		41,837
RING 5	2 to 3		42,235
RING 4	2 to 3		42,571
alpha ring	7 to 12		44,718
beta ring	7 to 12		45,661
eta ring	0 to 2		47,176
gamma ring	1 to 4		47,627
delta ring	3 to 9		48,299
Cordelia		~20	49,752
1986U1R	1 to 2		50,024
epsilon ring	22 to 93		51,149
Ophelia		~25	53,764
Bianca		~25	59,165
Juliet		~30	61,767
Desdemona		~30	62,658
Rosalind		~40	64,358
Portia		~40	66,097
Cressida		~30	69,927
Belinda		~30	75,255
Puck		~85	86,004
Miranda		236	129,850
Ariel		579	190,950
Umbriel		586	266,010
Titania		790	436,340
Oberon		762	583,510

*From center of Uranus.



Miranda

About one-sixth the diameter of Earth's moon, Miranda is the most surprising of the Uranian satellites, for its geologic diversity. Most of its terrain consists of old, heavily cratered and rolling plains. Overlying this older terrain are three very large, younger, oval features which bear little resemblance to any other real estate in the solar system. These "ovoids" are basically rectangular and between 200 and 300 kilometers (120 to 180 miles) in diameter. They are cut by deep, parallel ridges, grooves, and scarps. Large cliffs cut through both the ancient terrain and the ovoids. Some of these cliffs are as high as 20 kilometers (12 miles).

Some scientists suggest that Miranda's ovoids formed when Miranda may have melted early in its history, allowing the heavier rocky materials to sink toward its center. During this process, called differentiation, Miranda may have been fragmented several times by larger bodies, and then gravitationally reassembled, with the former core material now near the surface. The ovoids could be the scars left as the heavier material again sank through the viscous ice surface of the satellite. On the other hand, the ovoids could have been caused by rising masses of ice that broke through the surface. In either case, the process of differentiation was probably never completed: Miranda appears frozen at an early stage of its development.

Oberon's surface probably has not been reworked since the satellite formed. There is a large number of craters with diameters between 50 and 100 kilometers (30 to 60 miles). Bright material on the satellite's surface may be material ejected during the impacts that formed the craters. Oberon has at least one enormous mountain, at least 20 kilometers (12 miles) high that may be the central peak of a large impact crater.

Titania is the largest of the Uranian satellites, and its surface shows evidence of internal activity at one time. It has far fewer craters of the size found on Oberon, indicating that the larger, older craters have been erased by later cratering and global tectonics. Titania has many smaller craters and its surface is more heavily fractured than Oberon's. As the moon cooled and began to freeze, its watery interior froze and expanded, stretching the crust and producing the faults and graben we see in Voyager images. Titania has probably been relatively quiet for about three billion years.

Umbriel is the darkest of the major Uranian satellites, reflecting only about 19 percent of the sunlight it receives. Most of Umbriel is dark and bland, but it does have two large bright features near the equator: a ring 80 kilometers in diameter that covers the floor of an impact crater, and a spot on the central peak of another large crater. The bright material probably came from below the surface.

Ariel, as its name evokes, is the brightest of the Uranian satellites. Its surface is probably also the youngest (i.e, the most recently resurfaced, in geologic time). After a period of tectonic activity resulting in deep crustal faults, Ariel was probably resurfaced by volcanic activity. The volcanic material was probably a warm, plastic mixture of ice and rock with a glacier-like flow.

In late 1985, about a month before Voyager 2's closest approach to Uranus, the first of ten new satellites was discovered. The Voyager flight team was able to reprogram the spacecraft to capture an image of this satellite, now whimsically known as Puck. Puck is remarkably round for its size, and very dark. Puck is about 170 kilometers (100 miles) in diameter.

The remaining nine new satellites range in size from about 20 to 40 kilometers (12 to 24 miles) in diameter, and lie between the rings and Puck.

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JPL 410-15-81 3/88

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Voyager

BULLETIN

MISSION STATUS REPORT NO. 82 **MAY 9, 1988**

In the summer of 1989, Voyager 2 will once again make headlines as it adds the jewel of Neptune to its crown of accomplishments. The Neptune encounter will mark several milestones: the first spacecraft flyby of Neptune, the last planetary encounter by Voyager 2, the closest approach to any object by Voyager 2, and Voyager 2's twelfth birthday (it was launched on August 20, 1977).

Although Voyager 2 has been observing Neptune for more than a year, it will not be close enough to begin intensive, continuous studies until June 1989. Voyager 2's encounter of Neptune will span four months, from June 5 through October 2, 1989. On August 25, 1989 (Universal Time Coordinated), Voyager 2 will sail over the north pole of Neptune, within about 4,400 kilometers (2,700 miles) of the visible cloudtops. Five hours later, the spacecraft will pass about 40,000 kilometers (24,800 miles) from Neptune's large moon Triton.*

The Neptune encounter will be Voyager 2's closest encounter with any object in its 12-year odyssey through the outer solar system. [In 1980, Voyager 1 flew 3,915 kilometers (2,430 miles) from Saturn's haze-enshrouded moon Titan, while in 1986 Voyager 2 flew within 29,000 kilometers (18,000 miles) of the Uranian moon Miranda.]

The flyby distance has been chosen to provide data on magnetic fields and charged particles at Neptune, to probe deep into Neptune's atmosphere with Voyager's radio waves, and to bend Voyager 2's flight path close to Triton, while limiting the risk of damage to the spacecraft from ring particles, radiation, or atmospheric drag at Neptune.

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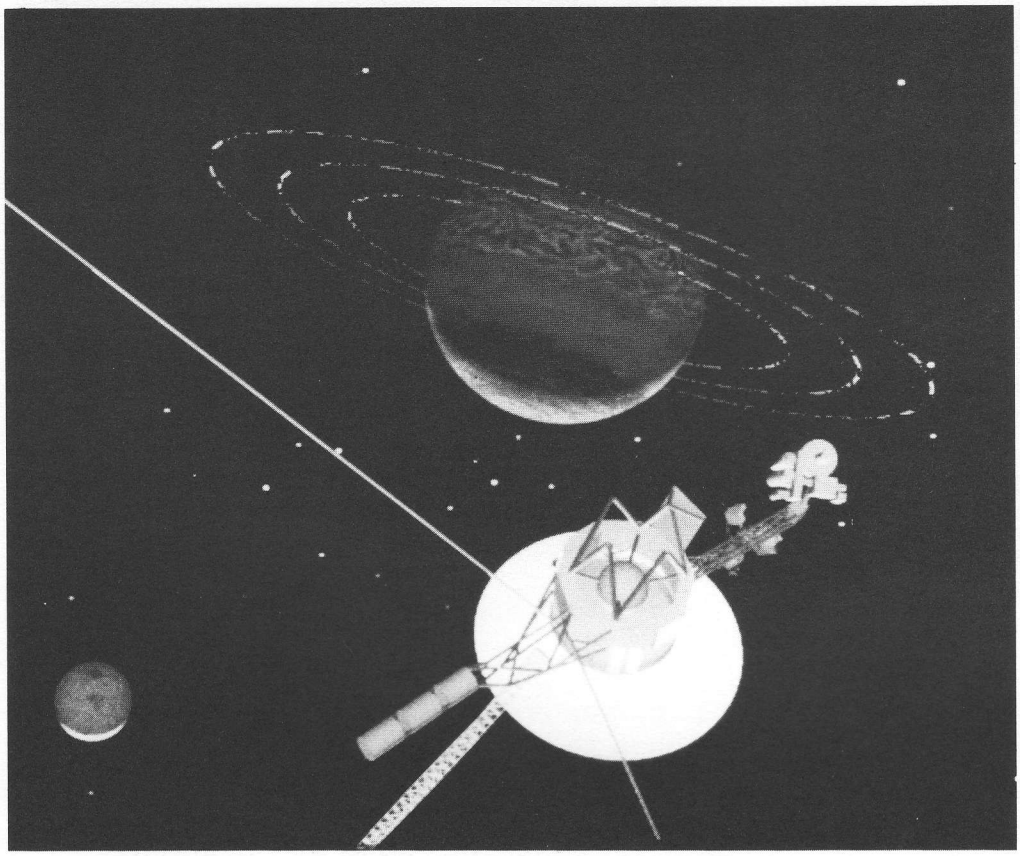
*Universal Time Coordinated (UTC) is referenced to the Prime (Zero) Meridian in Greenwich, England. The actual moment of closest approach will occur on August 25 at 0400 UTC (which is August 24, 9 p.m. PDT), although many of the observations being conducted about this time will be recorded on the spacecraft's digital tape recorder for transmission to Earth later. The spacecraft's radio signals at closest approach will not reach Earth until 1:06 a.m. PDT, August 25, because radio signals (traveling at the speed of light) will take 4 hours 6 minutes to cross the vast distance from Neptune to Earth.

Neptune, the Eighth Planet

Although Neptune is the fourth largest planet, it is invisible to the naked eye because it orbits in the outer regions of the solar system, 4.5 billion kilometers (nearly 3 billion miles) from the Sun. Even our biggest and best telescopes have been able to discern only meager details about the planet since its discovery.

In 1845, John Couch Adams of England accurately calculated the existence and location of the eighth planet, based on the motions of Uranus, but no one looked for it until 1846. Working independently, Urbain Leverrier of France also performed the calculations. Using the calculations of Adams, the English astronomer James Challis observed Neptune on August 4, 1846, but did not recognize it as a new planet. Using Leverrier's calculations, Johann Gottfried Galle, chief assistant of the Berlin Observatory, and student astronomer Heinrich Louis d'Arrest, identified the planet on September 23, 1846. Galileo may actually have observed Neptune 233 years earlier — but he did not recognize it as a planet.

At an average distance from the Sun of 30 astronomical units (AU) or 4.5 billion kilometers (2.8 billion miles), Neptune takes 165 years to travel around the Sun — nearly twice



Seven hours after its closest approach to Neptune and two hours after its encounter with Triton, Voyager 2 will be 475,000 kilometers (295,000 miles) from the planet and headed in a direction well below the ecliptic plane.

as long as it takes Uranus, which orbits at 19 AU (2.8 billion kilometers or 1.8 billion miles) once every 84 years.

At this distance, Neptune receives about 1,000 times less sunlight than does Earth, and about 2.5 times less than Uranus, but its overall temperature is about the same as that of Uranus. Therefore, Neptune must be generating some heat of its own.

Neptune is about the same size as Uranus, with a radius of about 24,760 kilometers (15,350 miles), but it is more dense, indicating that it must contain heavier materials than Uranus does. {The mean density of a planet is an important clue to its composition and structure. To calculate a distant planet's density, scientists first calculate its volume, which is proportional to the cube of its radius [$V = (4\pi/3)r^3$]. They then calculate the planet's mass based on the orbital size and period of the planet's satellites ($M = 4\pi^2a^3/GP^2$) or from perturbations in the orbits of nearby planets. The mass divided by the volume (M/V) gives the mean density.}

Both planets rotate at about the same rate — Uranus' internal rotation rate is 17.24 hours, while Neptune's rotation rate is thought to be about 17.8 hours. Rotation rates can be measured in two ways: by tracking cloud features in the atmosphere or by monitoring the radio emissions generated by electrons spiralling in the planet's magnetic field, which originates in the planet's interior. Tracking cloud features gives the true rotation period only if wind velocities are negligible, but it is the only method available when one is too far away to detect a planet's radio waves. The radio signals give the rotation rate of the bulk of the planet.

While Uranus is unique among the planets in that its rotational axis points toward the Sun, Neptune is more conventional. Its rotational axis is tilted only 29 degrees to the plane of its orbit around the Sun (Earth's axis tilts 23.5 degrees). So, as on Earth, the north pole of Neptune probably experiences midnight Sun in the summer while its south pole is cloaked in darkness. (Realize that seasons last more than 40 years on Neptune!)

Little has been learned about Neptune's atmosphere. At times, a thin atmospheric haze has been observed over half the planet. The haze comes and goes over a matter of days and weeks, and may be aerosol particles or ice crystals. The bulk of the planet is believed to be composed primarily of hydrogen, helium, and methane. If there are methane clouds on Neptune, they probably condense at a pressure level of about 2 bars (twice the mean surface pressure at sea level on Earth) and a temperature level of about 85 degrees Kelvin (-307°F). Voyager 2's radio signals can probe to a pressure

level of 3 to 5 bars, so there is a good chance of detecting methane clouds if they exist at Neptune. Although other cloud layers, including water ice clouds, are expected deeper in the atmosphere, Voyager will not be able to detect them.

Scientists expect that Neptune has a magnetic field, as do Mercury, Earth, Jupiter, Saturn, and Uranus. Penetration of the field by Voyager 2 is not likely until several hours before the spacecraft's closest approach to the planet.

Ring Arcs

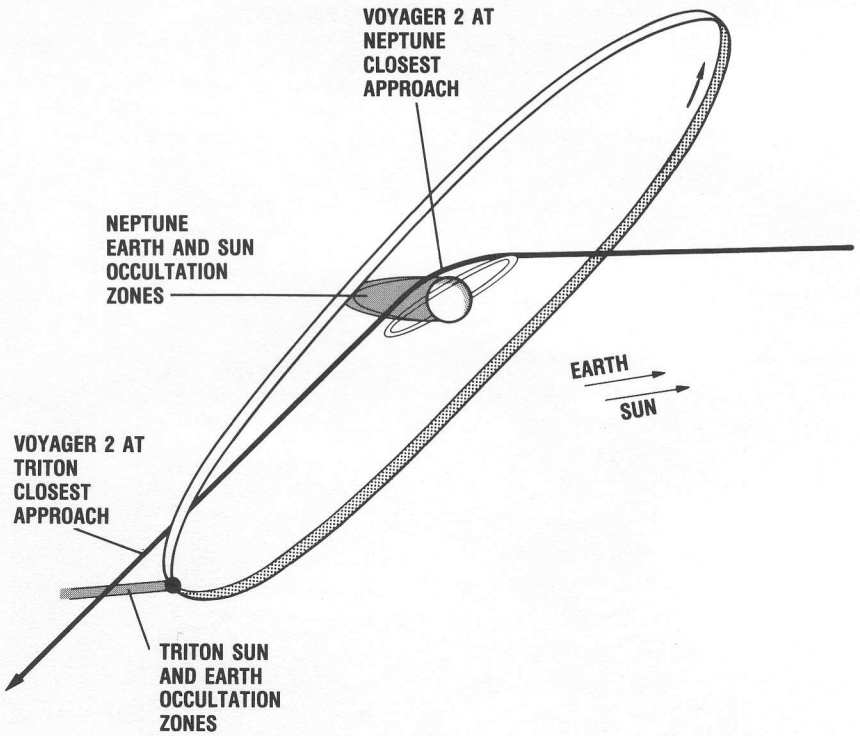
Does Neptune have rings? Maybe...and maybe not. Neptune may have a series of discontinuous ring arcs rather than rings that completely encircle it, as do Jupiter, Saturn, and Uranus.

A classic technique in ring searches is to monitor the brightness of a star as a planet's ring region passes in front of (occults) the star, as seen by the observer. Rings may be deduced if the starlight blinks on and off in a regular pattern on both sides of the planet. However, effects that may be due to ring material near Neptune have been seen in only 20 percent of occultation studies, and never have they been seen to occur on both sides of the planet. Scientists have had to deduce partial ring arcs to explain this result. Currently, scientists believe there are three narrow [8- to 20-kilometer (5- to 12-mile)], near-circular, partial arcs in or near Neptune's equatorial plane at a distance that is three times the planet's radius. The size of particles comprising these rings is estimated to range from 1 micron to 1 centimeter — from dust motes to pebbles.

Since the chosen flight path carries the spacecraft close to the region of the possible ring arcs, it is particularly worrisome to mission planners that the location of these ring arcs cannot be well defined until Voyager 2 is nearly there. Selected areas on the spacecraft are vulnerable to hits by dust-sized particles. Passage through a diffuse sheet of ring particles could result in several hits to the spacecraft, although the probability of a hit is less than one in a hundred. The current flight path will take the spacecraft outside the supposed position of the outermost ring arc, and the flight path can be adjusted as late as one week before the closest approach to Neptune if additional ring arcs are detected by then.

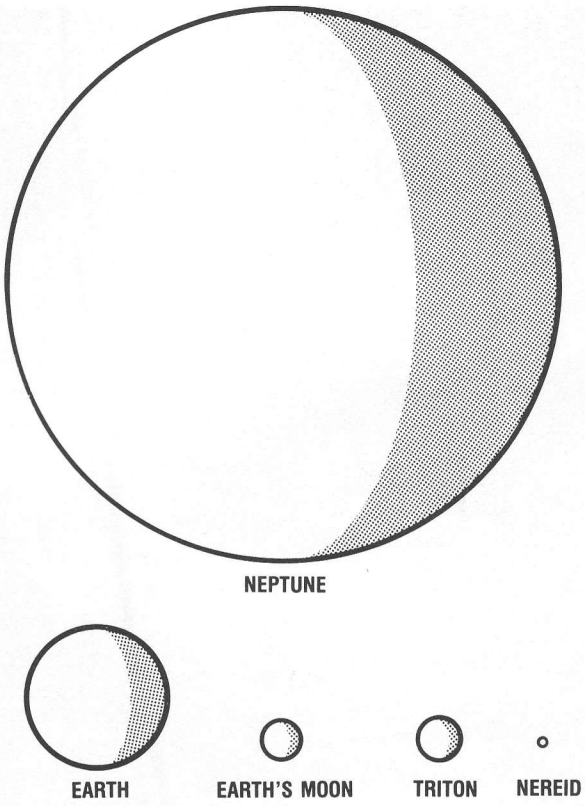
Radiation

The other giant planets — Jupiter, Saturn, and Uranus — all trap high-energy particles in their magnetic fields, creating regions of trapped radiation



Voyager 2 will approach Neptune from below the ring plane, ascending above the ring plane less than one hour before closest approach, and descending below the ring plane again about 1-1/2 hours after closest approach. The Sun and Earth occultation periods will last about 50 minutes at Neptune and four minutes at Triton.

that threatens the electronics on board the spacecraft. At Jupiter, Voyager 1's photopolarimeter instrument was fatally damaged, the ultraviolet spectrometer was rendered useless for a period of time, and the spacecraft experienced enough temporary radiation damage to confuse the spacecraft's internal clock, thus throwing off the synchronization between two of the computers on board the spacecraft by eight seconds. Among other effects, some images were smeared, or blurred. The computer sequences for Neptune are being carefully written to minimize adverse radiation effects on the observations, and Voyager 2's flight path has been chosen to avoid the regions where radiation may be the worst.



Triton and Nereid

Neptune has at least two satellites, Triton and Nereid. Neither travels in the plane of the planet's equator (Triton's orbit is inclined 160° to Neptune's equator, while Nereid's is inclined 28°).

Triton is roughly the size of Earth's moon, although its radius may be anywhere from 1,100 to 2,500 kilometers (680 to 1,550 miles). Triton is the only large moon in the solar system to be in a retrograde orbit (it travels in the opposite direction of the planet's rotation). Because of its retrograde orbit, Triton is slowly falling toward Neptune: in 10 billion years or so, Triton will be destroyed by tidal forces as it nears the planet.

Triton's surface may be covered with methane ice and shallow lakes of liquid nitrogen. Scientists believe Voyager may be able to see through Triton's atmosphere to the surface, unlike the case of Saturn's moon Titan, where the atmosphere was too thick to permit pictures of the surface, although Voyager's infrared and radio studies probed to the surface.

With clever programming of the spacecraft, the best Voyager images of Triton are expected to show features as small as one kilometer (0.62 mile) — or nine football fields — across from a distance of 40,000 kilometers (25,000 miles).

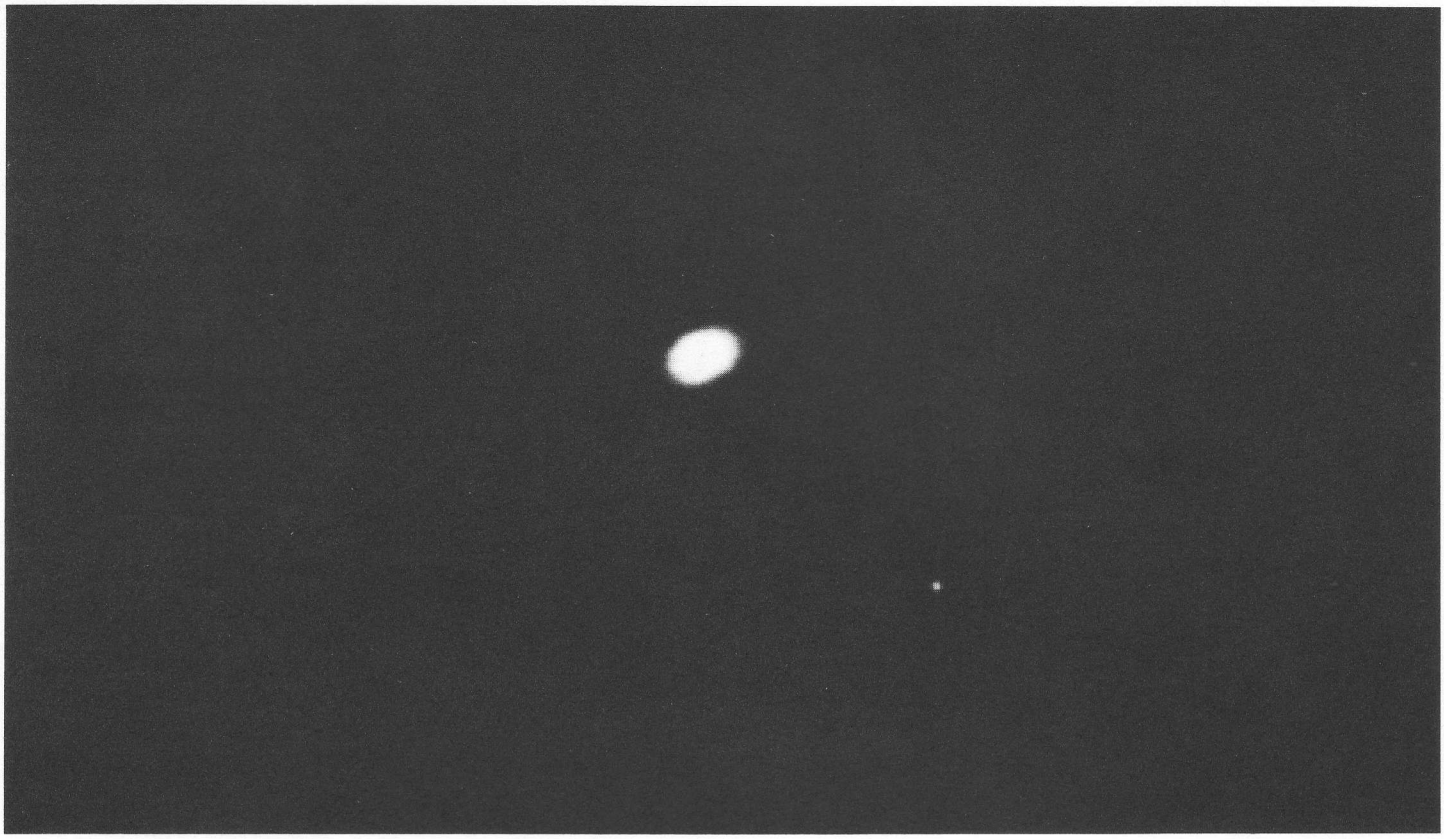
Triton was discovered by William Lassell of England in 1846, less than a month after the discovery of Neptune. In 1949, more than a century later, Gerard Kuiper of the U.S. photographed a second moon of Neptune, tiny Nereid.

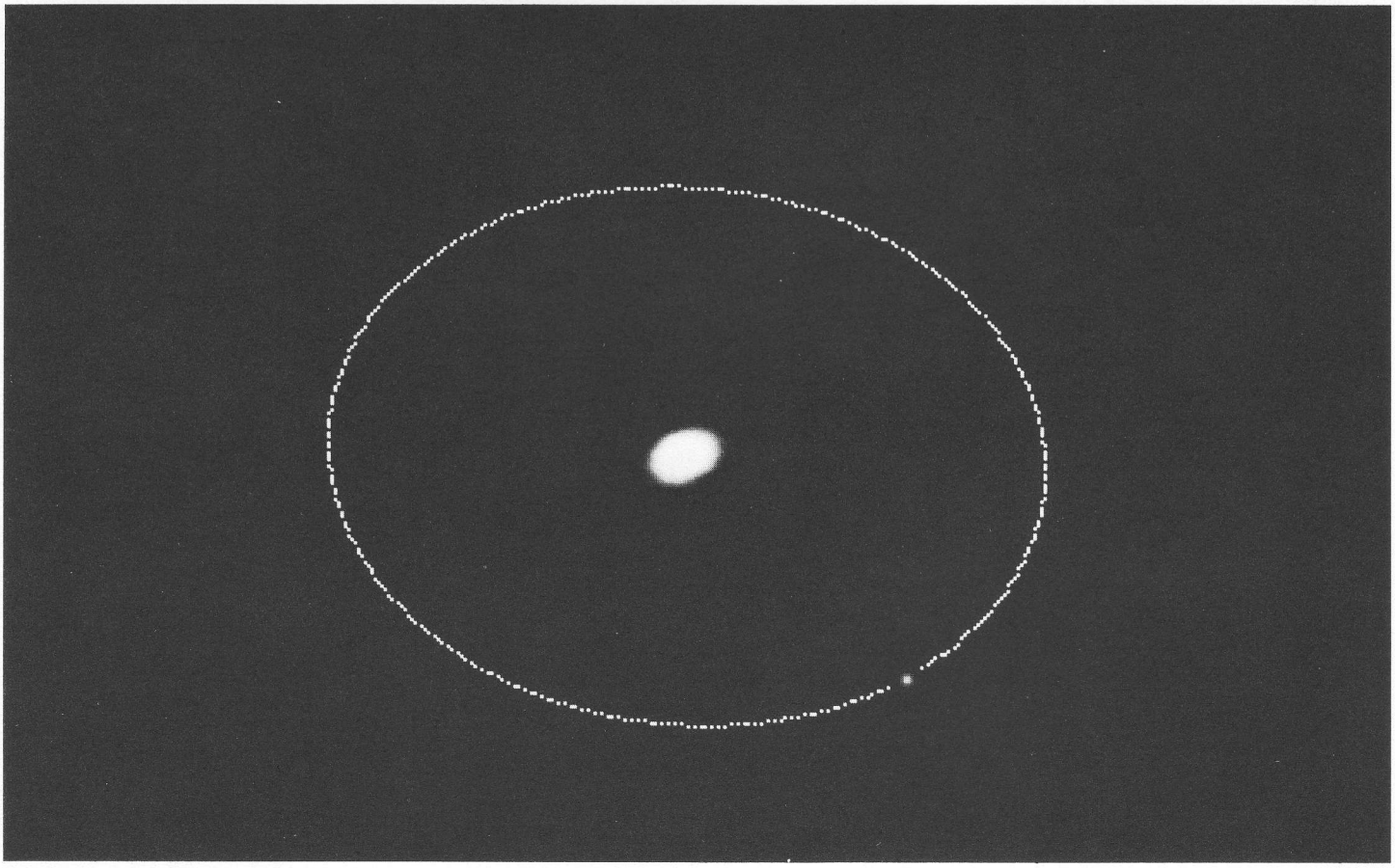
Nereid is between 300 and 1,100 kilometers (190 to 680 miles) in radius. Voyager 2 will pass 4,655,000 kilometers (2,890,000 miles) from Nereid.

Voyager's Objectives at Neptune: an Overview

NASA's plan for exploring the solar system begins with

Right: The planet Neptune and its satellite Triton were photographed by Voyager 2's television camera on January 16, 1987, from a distance of 1.4 billion kilometers (850 million miles). This picture is roughly comparable with Earth-based resolution. (The lower image is inscribed with Triton's orbit.) Triton, the bright spot at five o'clock, is about 3,500 kilometers (2,200 miles) in diameter; Neptune's diameter is 49,520 kilometers (30,700 miles). Neptune appears oblong because of smear induced by the long exposure of 5.76 seconds. Triton has been brightened artificially so that it is apparent on the photo print. This image was taken with Voyager's narrow-angle camera through a clear filter as an aid to the Voyager navigation team.





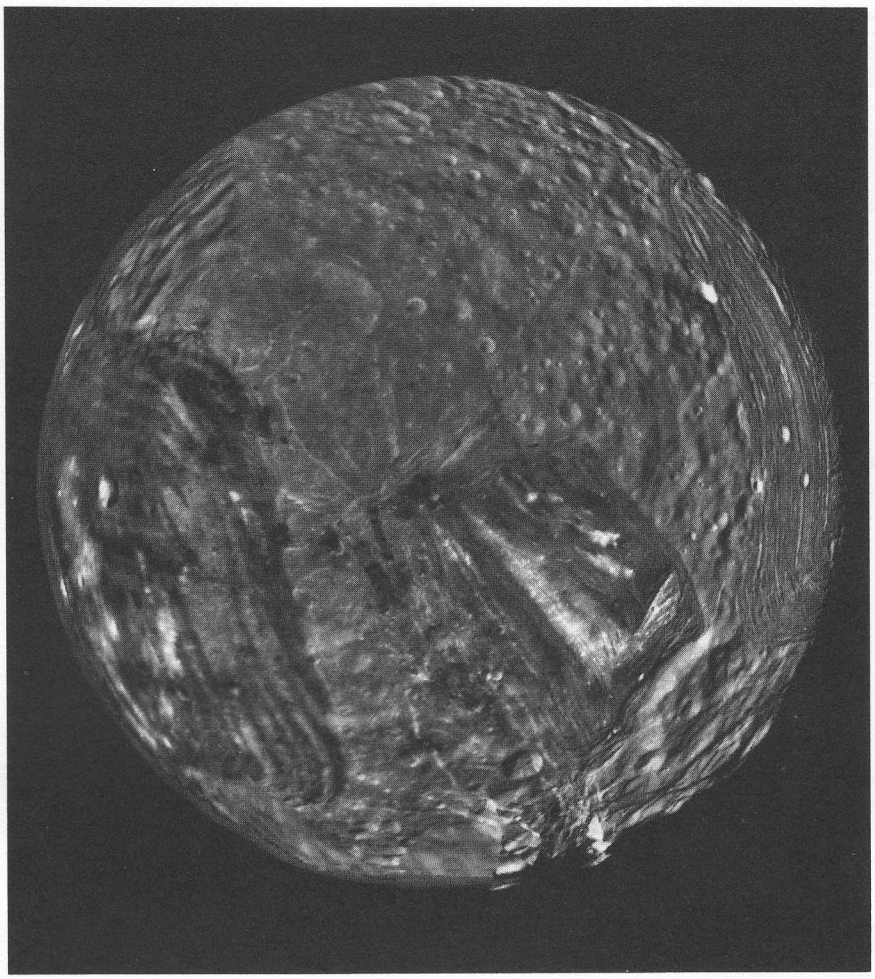
flybys of each planet, followed by more in-depth reconnaissance, and then by detailed, extended observations. With the Voyager flyby of Neptune, NASA will have completed flybys and initial reconnaissance of all planets in our solar system except Pluto. (Neither of the two Voyager spacecraft can be redirected to Pluto, and no mission to Pluto is currently planned.)

The knowledge gained so far has greatly extended comparative studies of planetary systems. At Neptune, Voyager 2 will obtain high-resolution images of the planet, its rings, and Triton, and penetrate the core of Neptune's magnetosphere. Voyager's radio waves will probe the atmospheres of both Neptune and Triton, and its imaging cameras will search for new rings and satellites.

The Voyager flight team faces several challenges at Neptune, including low light levels, longer communications distances, and an aging spacecraft.

At 30 AU, the light intensity is less than half of what was available at Uranus. Due to the low light levels, longer exposures will be required to capture images. But due to the high relative velocities between the spacecraft and its targets, long exposures result in smeared images, much the same as the blurred photos tourists shoot out of the windows of fast-moving buses.

To compensate, the flight team is further enhancing techniques employed for the Uranus encounter and adding new capabilities: Voyager 2 will use three techniques of image-motion compensation; one technique was used at Saturn and Uranus, while two new techniques have never before been used by Voyager.



Without the image-motion compensation technique devised by the Voyager flight team, the image at left, with a resolution of about 26 km (16 mi), would have been the best resolution obtained at Miranda. The mosaic above is composed of images taken from distances of 30,160 to 40,310 km (18,730 to 25,030 mi); resolution ranges from 560 to 740 meters (1,840 to 2,430 feet). This technique allows the spacecraft to drift at a controlled rate to track the target body and reduce image smear caused by high relative velocities between the spacecraft and the target.

"Classical" image-motion compensation requires that the entire spacecraft turn to track the target, and this points the communications antenna away from Earth. Data cannot be transmitted during this time and must be placed on the spacecraft's tape recorder for later playback to Earth.

Nodding image-motion compensation will briefly "nod" the spacecraft off Earthpoint less than 0.1 degree for a matter of seconds while the exposure is made. These rates are slow: 10 times slower than the hour hand of a clock. But even a few microradians per second of uncompensated motion will result in a smeared image. Bill McLaughlin, former manager of Voyager's Flight Engineering Office, notes "The 800-kilogram [1760-pound] Voyager spacecraft is being manipulated with a jeweller's precision" from a distance of 3 billion miles!

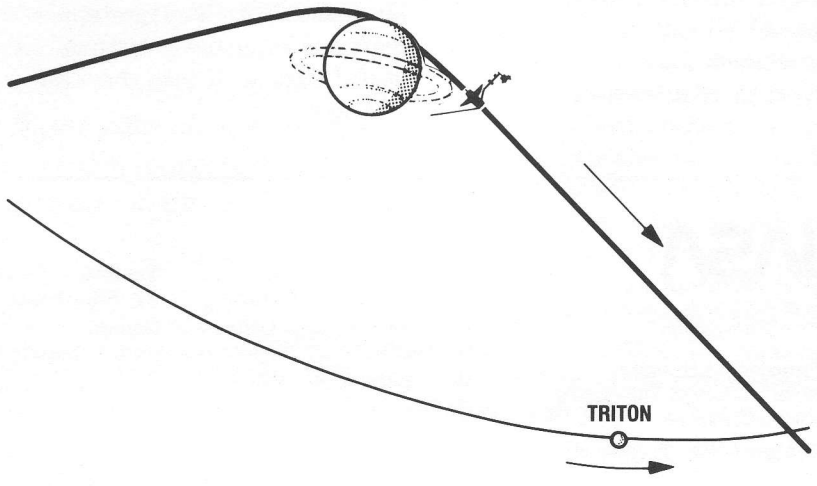
Maneuverless image-motion compensation utilizes scan-platform motion during data-taking for wide-angle images and for infrared data.

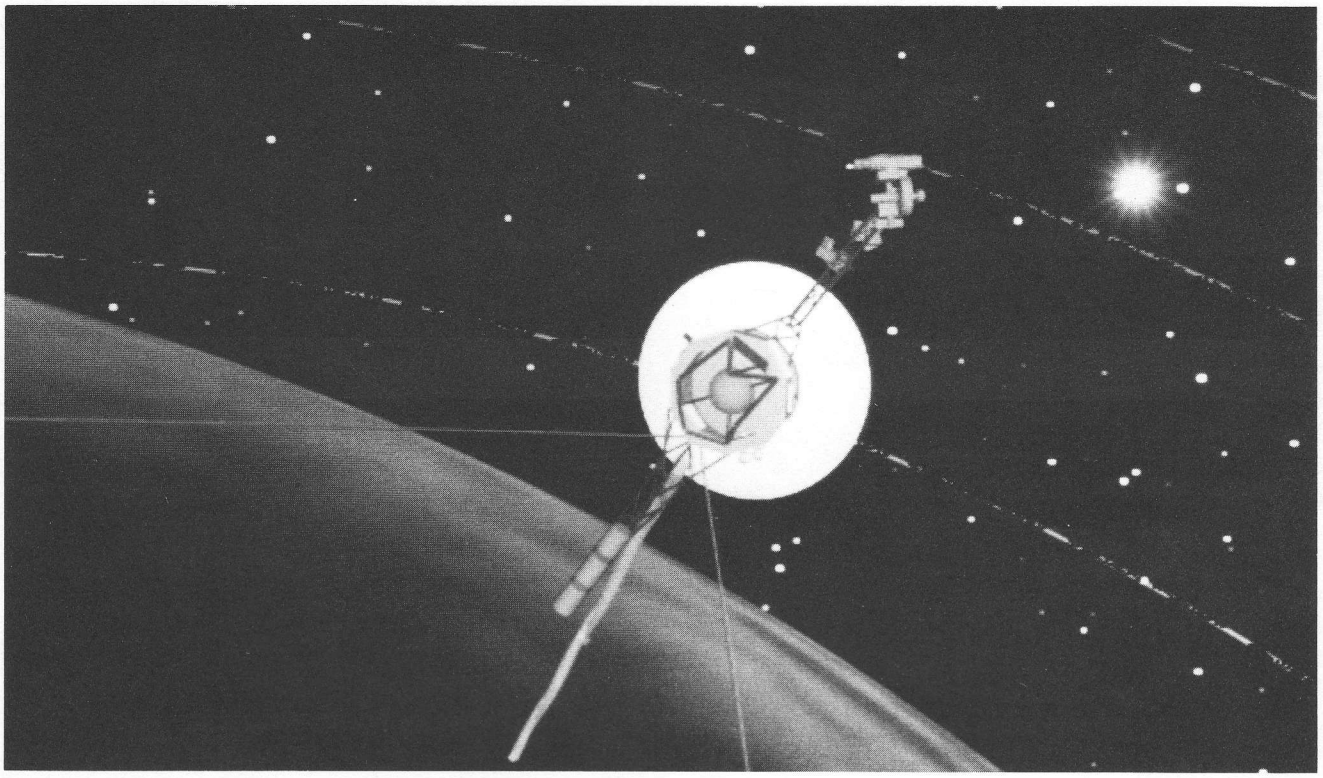
Voyager 2 is also being steadied as an observing platform. Normally, the spacecraft is steadied by short (10 milliseconds) bursts of hydrazine propellant from its attitude control thrusters whenever the spacecraft senses that it has drifted off its proper orientation by a few tenths of a degree. For the Uranus encounter, flight engineers reduced the thruster bursts to five milliseconds, and for Neptune the bursts will be shortened to four milliseconds, reducing the spacecraft's rotational rates by an additional 20 percent.

A third effort to gain the best images from Neptune involves changes in software on the ground and on the spacecraft. Previously, exposures longer than 15 seconds had to be recorded on the spacecraft's digital tape recorder for later playback to Earth. While typical exposures at Neptune will be as long as 15 seconds, the software changes will allow the spacecraft to obtain non-recorded images with exposures as long as 30 minutes, aiding searches for faint, diffuse ring material and small new satellites.

As Voyager speeds through the outer solar system, the radio signal from its 20-watt transmitter (the same wattage as the light bulb in a refrigerator) gets progressively fainter. Either a more sensitive receiver or larger antennae are needed to track this signal and more power is needed to transmit to the spacecraft across the vast distance. Although the spacecraft will be 1.6 billion kilometers (one billion miles) farther away, the communications rates at Neptune will be about the same as they were at Uranus due to improvements in the Deep Space Network that tracks and communicates with the spacecraft. Each of the three Deep Space Communications Complexes (located in California, Spain, and Australia) has one large antenna and several smaller ones. The large antennas are being enlarged from 64 meters (210 feet) in diameter to 70 meters (230 feet), and a new, high-efficiency 34-meter (111-foot) antenna has been built in Spain. The 70-meter antennas have also been enhanced for higher efficiency data collection. The signal received at several antennas can be electronically combined to produce a stronger signal (this technique is called "arraying" the antennas). For the Neptune encounter, the Australian station will again array with the Australian government's Parkes Radio Observatory, as they did for the Uranus encounter. In addition, the California stations will array with the 27 25-meter (82-foot) antennas of the Very Large Array in New Mexico. Also, Usuda Observatory in Japan will collect (simultaneously with the Australian stations) radio science data during the critical Neptune and Triton occultation periods on August 25, 1989 (UTC).

Voyager 2 will dive over the north pole of Neptune and encounter Triton as the spacecraft departs south of the ecliptic.





As Voyager 2 passes behind Neptune, the radio and ultraviolet spectrometer will be used to study the rings and the planet's atmosphere while looking back at the distant Sun and Earth.

Conclusion

When the Voyager mission was conceived, the design philosophy was to launch two spacecraft, a primary and a backup. If the primary spacecraft fulfilled the basic mission objectives of returning data from Jupiter and Saturn, then the second spacecraft could be used less conservatively at Saturn, and its mission could be extended to Uranus and Neptune, planets never before visited by spacecraft.

The accomplishments of the Voyager mission have far exceeded all expectations, and now we look forward to one more rush of discovery — for a planetary encounter, especially the first, is an exhilarating, never to be forgotten experience.

As it whips past Neptune at 28 kilometers per second (more than 17 miles per second), Voyager 2's flight path will be bent to send it *below* the ecliptic plane at an angle of about 48° (Voyager 1 is headed about 35° *above* the ecliptic plane). Its voyage of discovery will continue, as it joins Voyager 1 and Pioneers 10 and 11 in their investigation of the heliosphere and ultimately enters interstellar space. Both Voyager spacecraft are expected to return useful data well into the 21st Century.

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JPL 410-15-82, Rev. 1 10/88

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Voyager
BULLETIN
MISSION STATUS REPORT NO. 83 AUGUST 1, 1988

Neptune Images

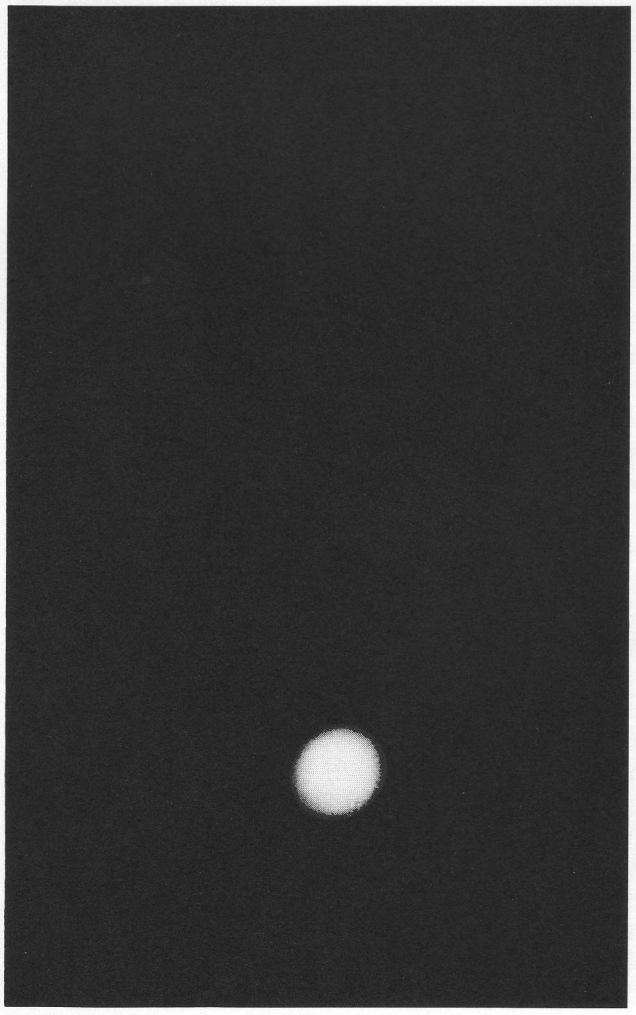
The resolution of Voyager 2 images of Neptune now exceeds that of Earth-based images. Neptune is now about 8 pixels (picture elements) in diameter (a Voyager image frame is 800×800 pixels). The image below was reconstructed in color from images taken through Voyager 2's narrow-angle camera's clear and green filters, using data from Earth-based telescopes to aid in the process.

Because Triton still appears smaller than a pixel, its image has been enhanced to 40 times its natural brightness to make it visible. Triton is closer to the viewer than is Neptune in this image.

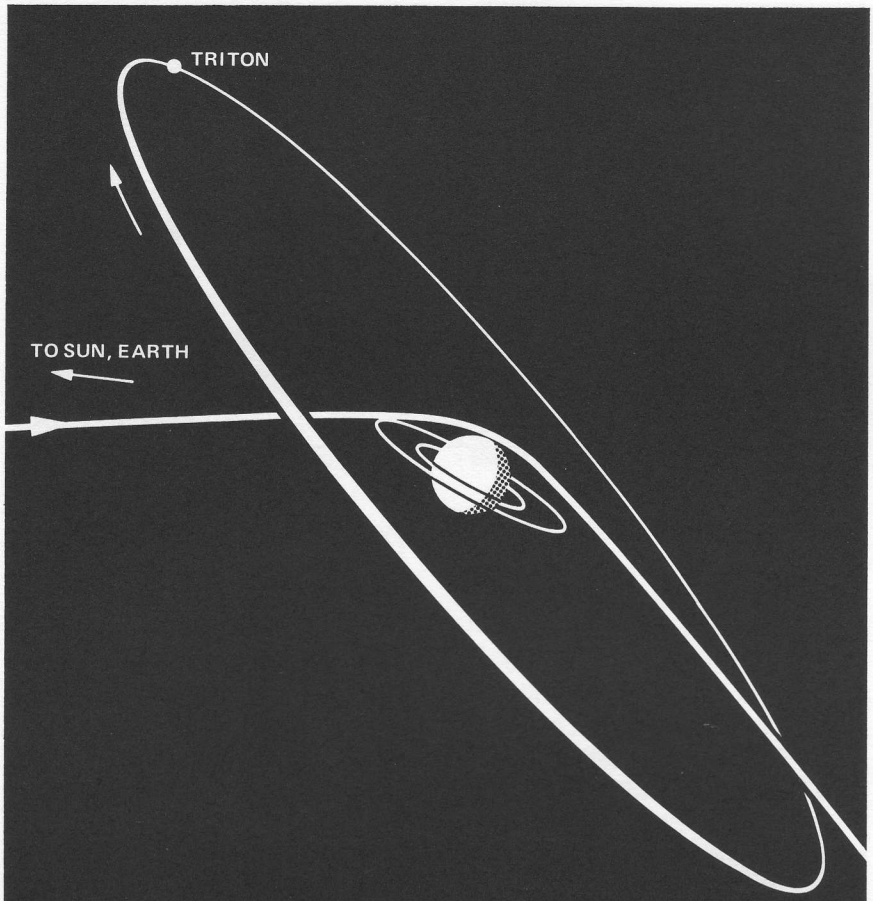
Neptune appears elongated because of slight spacecraft motion during the long (15-second) exposure, and appears bluish-green because methane gas in its atmosphere absorbs longer red wavelengths. Neptune is about 49,530 kilometers (30,780 miles) in diameter.

Scientists expect to be able to see giant cloud systems on Neptune as Voyager 2 continues to approach the planet. Closest approach to the planet will be on August 25, 1989.

Triton appears reddish-yellow, an effect caused by absorption of ultraviolet and blue wavelengths. Organic materials derived from methane may exist on the moon's surface or in its atmosphere. Triton is about 3,600 kilometers (2,200 miles) in diameter. It orbits Neptune at about 355,000 kilometers (220,600 miles) and is retrograde—it orbits in a direction opposite that of Neptune's rotation. The plane of its orbit is inclined about 160° to Neptune's equator. It is believed that Triton always keeps the same face toward Neptune (a phenomenon known as synchronous rotation).



Voyager 2 captured this inbound view of Neptune and its large moon Triton on May 9, 1988 from 685 million kilometers (426 million miles).



The positions of Neptune and Triton are shown on May 9, 1988, when the image on page 1 was obtained. This view is shown at a 90° angle from the flight path.

The spacecraft is inbound from the left. Triton is in a retrograde orbit at an angle of 160° to Neptune's equator and a period of 5.88 days.

What does Neptune look like?

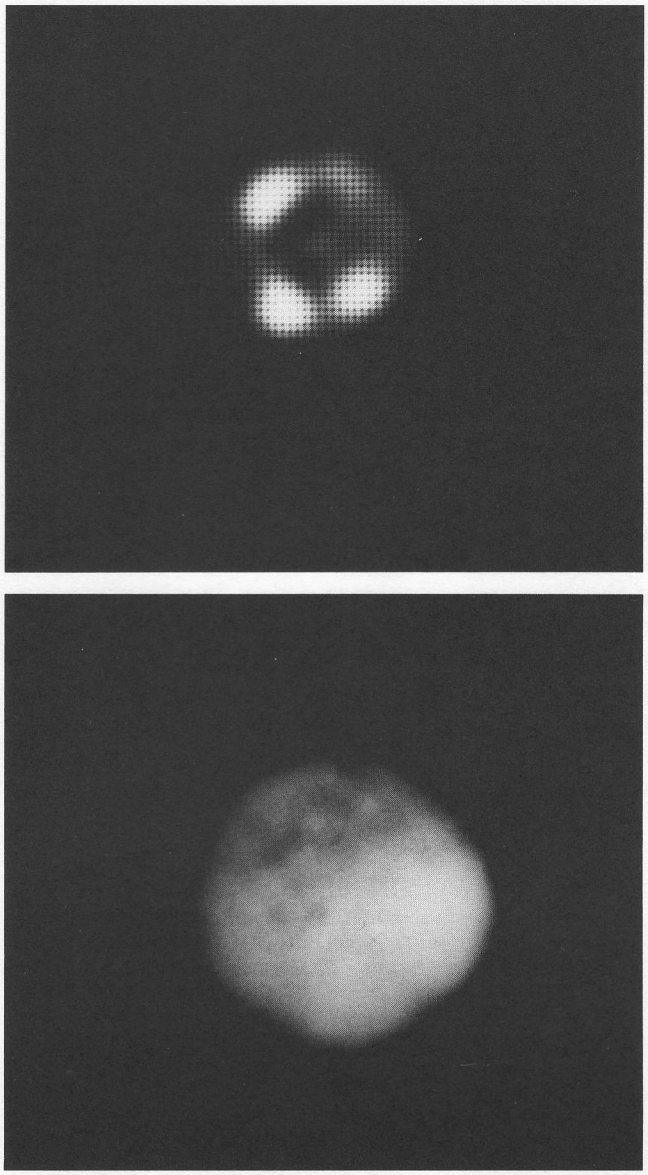
What will Neptune look like as Voyager 2 sails ever closer? Will we see the wild and brilliant oranges and whites of Jupiter? The muted butterscotch of Saturn? Or the tranquil blue of Uranus? The answer is probably none of these. What we will see in Neptune's atmosphere depends upon what gases are in the atmosphere, the temperature of the planet, what chemical processes are taking place, the wind speeds on the planet, and other effects. At 30 AU, the amount of sunlight that Neptune receives is 900 times less than what Earth receives, and less than half of what Uranus receives. And yet, Neptune's temperature is almost identical to that of Uranus. This must be due to heat coming from Neptune's interior. The low level of incoming light and heat and much higher (than Uranus) level of internal heat are sure to have a profound effect on processes in Neptune's atmosphere.

While Neptune's atmosphere is primarily composed of hydrogen and helium (as are the atmospheres of the other outer planets), about two-and-one-half to three percent of the atmosphere is methane (on Earth we commonly know it as "natural gas"). The methane at Neptune absorbs longer wavelengths of red light, and thus only the blues and greens are reflected to us, giving Neptune its bluish-green color.

Voyager 2 is still more than a year and more than 600 million kilometers (370 million miles) from Neptune. In images taken to help navigate the spacecraft, the planet appears featureless. However, using Earth-based telescopes, astronomers have seen large-scale bright cloud features on the planet that have changed over the last several years. Although these features are seen at infrared wavelengths inaccessible to Voyager, as the spacecraft continues to approach the planet, similar features should become apparent in Voyager images.

Each Voyager spacecraft carries a narrow-angle 1500-mm reflector telescope and a wide-angle 200-mm refractor telescope. Each is equipped with a vidicon (a TV camera tube), shutters, filters, power supply, and other electronics. Each camera has eight filters: two clear, two green, and one each of violet, blue, orange, and ultraviolet on the narrow-angle camera, and blue, clear, violet, sodium (yellow), green, orange, and two methane filters on the wide-angle camera. Thus, the cameras can detect wavelengths in the range from 3450 angstroms (ultraviolet) to 6200 angstroms (visible orange). (The human eye can see in the range from about 3800 to 6800 angstroms.)

In May 1983, photographs of Neptune taken from Earth showed three bright cloud features—each about the size of Earth—rotating around Neptune. Two were in the southern hemisphere and one in the northern hemisphere. The images were taken by Dr. Richard Terrile of JPL and Dr. Bradford Smith of the University of Arizona, using a highly sensitive charge coupled device (CCD) camera and a planetary coronagraph on the



Images taken from Earth-based telescopes in 1983 (top) by Terrile and Smith and in 1986 (below) by Hammel show dynamic changes in Neptune's atmosphere.

2.5-meter du Pont Telescope at the Carnegie Institution's Las Campanas Observatory in Chile. They observed in the 8900-angstrom wavelength band, a methane band (one angstrom is one ten-billionth of a meter). The clouds are believed to consist of methane ice crystals very high in Neptune's gaseous atmosphere. The clouds are thought to be higher than the rest of the visible atmosphere. They reflect sunlight before it penetrates deep enough in the atmosphere to be absorbed by the methane and thus the clouds appear brighter than the rest of the planet.

Images taken since 1986 by Dr. Heidi Hammel of JPL, using a CCD on the University of Hawaii's 2.2-meter telescope at Mauna Kea Observatory in Hawaii, show that the bright cloud in the northern hemisphere is now gone. Dr. Hammel observed a general brightening in the southern hemisphere at several different methane wavelengths, including one (6190 angstroms) that is the same wavelength as the methane filter on Voyager's wide-angle camera. By the spring of 1989, cloud features may become apparent in Voyager images taken through the methane filter.

Frederick L. Scarf

Dr. Fred Scarf, principal investigator for Voyager's plasma wave science investigation, died July 17 in Moscow. Dr. Scarf had been in Moscow to attend an international space meeting; he was co-investigator for the plasma wave investigations on the Soviets' dual-spacecraft Phobos mission to Mars, launched July 7 and 12.

Dr. Scarf, a theoretical physicist, was chief scientist for space research and technology at TRW, Inc., in Redondo Beach, CA. He was a principal investigator on Pioneers 8 and 9 and the Pioneer Venus Orbiter, and was instrumental in diverting the Earth-orbiting International Sun-Earth Explorer-3 [renamed International Cometary Explorer (ICE)] satellite to study the comet Giacobini-Zinner several months before an international spacecraft armada reached Halley's Comet. He was involved in several programs of the European Space Agency and the Japanese space program.

The Voyager Project extends its deepest sympathy to his family. Plans for a memorial scholarship are pending.

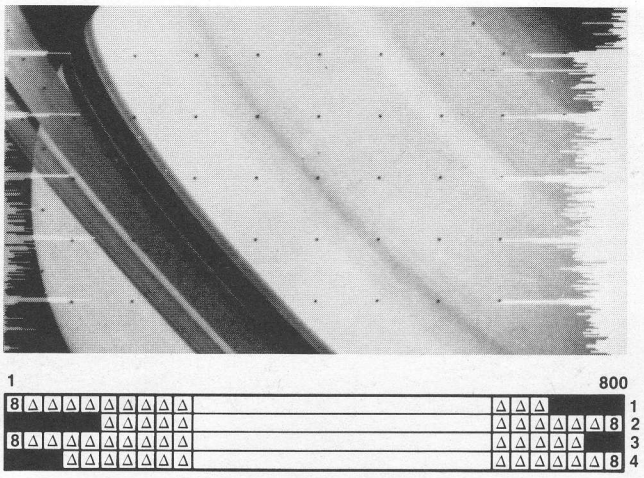
Dual Processor Programs and VLA/ Goldstone Array

Voyager 2 has completed an important test this summer of its onboard computing, data receipt, and data processing on the ground in preparation for next summer's Neptune flyby. The test exercised software, hardware, and procedures that will be critical during the Neptune encounter.

Uranus is at about 20 astronomical units (AU), while Neptune is at about 30 AU. Over such a long distance, the possibility of corrupting or losing data increases—consider that a single image consists of over five million bits of data—800 lines by 800 picture elements (pixels) per line times 8 bits per pixel—and then imagine these bits strung out across 4.5 billion kilometers on their way to Earth!

Two techniques have been devised to reduce the number of bits to return images: data editing and data compression. Data may be edited either by deleting some pixels, resulting in reduced resolution of the image, or by returning only part of the scene, but at full resolution. In data compression, the absolute brightness of the first pixel of each line is sent, and then the brightness of each succeeding pixel in the line is expressed as its difference from the preceding pixel. This technique reduces the total number of bits needed to transmit an image, but preserves full size and full resolution. This reduces the bit volume by 60 to 70 percent, depending on the data format.

To accomplish this data compression, both processors of the flight data subsystem (FDS) are required. Normally only one processor is active at a time; the second is reserved as backup in case the first should fail. The program that performs this data compression is part of a pair of programs known collectively as the Neptune dual processor programs.



By transmitting only the first pixel in each line, and then the difference between adjacent pixels in the remainder of the line, the number of bits per image can be greatly reduced.

The objectives of the Neptune Dual Processor Programs and Very Large Array/Goldstone Telemetry Array test were to exercise all of the spacecraft's data modes that will be used for encounter, to exercise modifications of the control functions for the imaging cameras, and to perform instrument checkouts or source calibrations which require the dual processor programs. In addition, this test provided the only opportunity before encounter operations begin to test the array of the Very Large Array (VLA) in Socorro, New Mexico, and the Goldstone Deep Space Communications Complex in Goldstone, California at the high data rates being planned for use during the Neptune encounter.

The technique of electronically combining the signals received at different antennas serves to increase the probability of reliably capturing the spacecraft's faint signal, by increasing the effective antenna size. The North American array will link signals from two to three antennas at Goldstone—one 70-meter dish and one or two 34-meter dishes—with the twenty-seven 25-meter (82-foot) antennas of the VLA. During the Neptune encounter, the network must capture data coming from the spacecraft at two rates: 14,400 bits per second (bps) of imaging data and of general science and engineering (GS&E) data, and 21,600 bps that contain both real-time and tape-recorded imaging and GS&E data. The data from the VLA will be sent via satellite link to Goldstone, where the data will be combined.

The Goldstone-VLA link was tested five times this summer, starting with simple tests and progressing to the full menu—the highest data rates and more complex configurations—required for Neptune encounter next summer.

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JPL 410-15-83 8/88

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Voyager

BULLETIN

MISSION STATUS REPORT NO. 84 **JANUARY 30, 1989**

Update

Voyager 2 is 4.36 billion kilometers (2.71 billion miles) from Earth. Neptune lies 298.95 million kilometers (185.76 million miles) and slightly more than six months ahead. With a velocity of about 18.9 kilometers per second (42,380 miles an hour), Voyager 2 travels over a million miles a day.

The radio science team is completing an eight-week period of solar observations. Each year, when the Earth moves to the opposite side of the Sun from the spacecraft, the spacecraft's radio signals can be used to probe the atmosphere of the Sun. Strong, measurable changes occur in Voyager 2's radio signal as the signals pass through the solar corona. Radio scientists will study small-scale (about 100 kilometers) variations of plasma (hot ionized gases) in the solar region, as well as map the plasma density of the solar wind and corona.

Encounter Period Overview

The Neptune encounter period will officially begin on June 5, 1989, eighty-one days before Voyager 2's closest approach to Neptune. The first 62 days are called the "observatory" phase, and will consist of continuous observations of the Neptunian system and numerous pre-encounter calibrations (checkouts) of Voyager 2's instruments. Science observations will include repeated scans across the entire Neptunian system with the ultraviolet spectrometer to look for neutral hydrogen and excited ions. The imaging cameras will monitor long-term atmospheric motion on the planet and search for ring arcs and satellites. A trajectory correction maneuver is scheduled for August 1.

On August 6, 1989, nineteen days before closest approach, the "far encounter" phase will begin. By then, at least two narrow-angle camera frames will be required to capture the entire planet and the ring-arc region. Satellite observations, detailed ring observations, and infrared observations of Neptune will begin. Two trajectory correction maneuvers are scheduled during this period, on August 15 and August 21, to fine-tune the spacecraft's flight path.

The "near encounter" period, from August 24 to August 29, will contain all of the highest value Neptune science, including a distant look at tiny Nereid, a close swing over Neptune's north pole, and a close look at Triton, as well as characterization of Neptune's magnetic field and searches for possible ring arcs and other satellites.

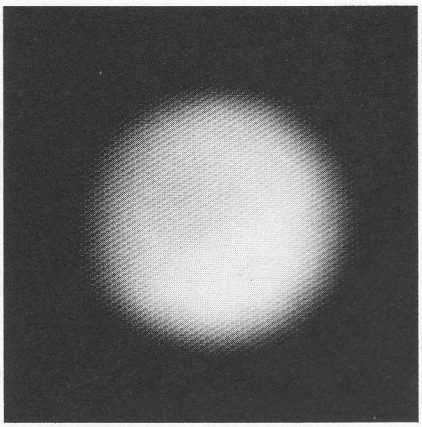
Voyager 2 will pass about 4,850 kilometers (3,000 miles) above the cloudtops of Neptune at about 76° north latitude (which would be far north of the Arctic Circle on Earth, for example). This will be Voyager 2's closest approach to any object in the solar system since it left Earth nearly twelve years ago.

Voyager 2's aimpoint at Neptune has been carefully chosen to bend the flight path sharply below the equator again, where Voyager 2 will intercept Neptune's large moon Triton at a distance of about 40,000 kilometers (25,000 miles) five hours after the spacecraft's closest approach to Neptune.

Once past Neptune, Voyager 2 will continue to observe the Neptunian system on a continuous basis for five more weeks, until October 2, 1989. Observations of the dark side of Neptune and post-encounter calibrations will be important activities during this post-encounter period.

Neptune will be Voyager 2's last planetary encounter, but the spacecraft's job will be far from over. Both Voyagers 1 and 2 will continue to return data on magnetic fields and charged particles in space, and their ultraviolet spectrometers will continue to observe ultraviolet sources among the stars. Voyager 2 will

Images of Neptune taken over a five-and-one-half hour period on July 14, 1988 clearly show cloud features moving across the disk as the planet rotates. These Images were taken at 6190 angstroms, the same wavelength as the methane-band filter on Voyager 2's wide-angle camera. (Times shown are GMT.) (H. Hammel, JPL)



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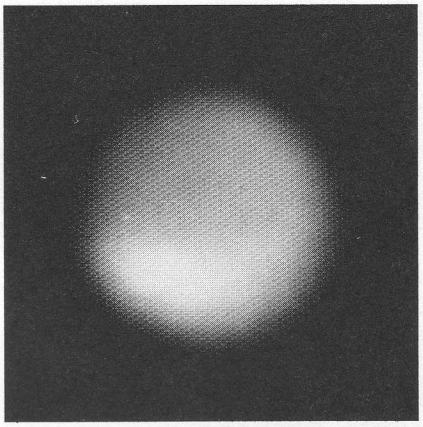

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also join the search for the edge of the heliosphere, that area of space dominated by the Sun's magnetic field. The planetary adventures of Voyager 1 and Pioneers 10 and 11 are over and they are already searching for the heliopause, a boundary region between the Sun's magnetic influence and interstellar space. Scientists will recognize that the spacecraft is approaching the heliopause when the spacecraft senses the termination shock where the solar wind, traveling at supersonic velocities up to a million miles an hour, abruptly decreases to about one-fourth that velocity. Perhaps by the next century, one of these spacecraft will pass beyond the heliopause into true interstellar space.

Spring '89 Overview

Test and Training

In preparation for the first-ever encounter with Neptune, the Voyager Flight Team is undergoing a program of training and tests to familiarize all Flight Team personnel with the equipment, software, data formats, facilities, procedures, and interfaces to be used during and in support of Neptune encounter operations.

The training started in October 1988 with intra-team training. Integrated flight team training began in late January and will culminate in late May 1989 with a full dress rehearsal simulation of near-encounter activities. The near-encounter test (NET) will simulate an intensive 12-hour period of events that will occur during the real encounter in late August. The intent is to demonstrate that the spacecraft and all personnel, equipment, software, and procedures—both at JPL and within the Deep Space Network and its affiliated tracking stations—will perform as required to capture the encounter data. As in the past, the test and training exercises are intended to ferret out problems that need to be solved before encounter.

A trajectory correction maneuver (TCM) is currently scheduled for April 20. This maneuver will target Voyager 2's flight path closer to the desired aimpoint at Neptune by about 3,800 km (2,400 miles). Voyager 2 will be instructed to expend some of its hydrazine propellant to obtain a velocity change of about 0.35 meters per second (less than one mile per hour).

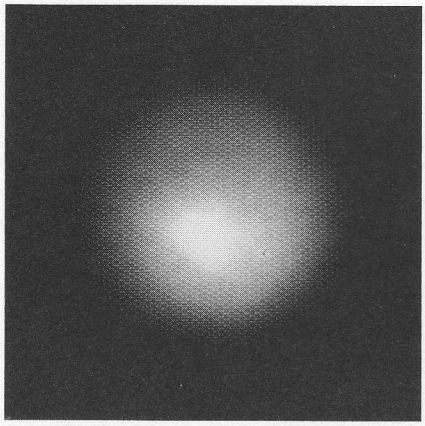
This TCM is a test of a new technique in which the spacecraft's antenna will continue to point toward Earth during the maneuver. The directional change will be achieved by causing the spacecraft to drift in the desired direction by commanding a series of turns about the roll axis.

During a typical TCM, the spacecraft is first re-oriented (usually causing the antenna to point away from Earth, and thus temporarily making it impossible to communicate with the spacecraft), and then hydrazine propellant is expelled from the thrusters, giving the desired velocity change in the desired direction.

There are at least two benefits of the new roll-turn technique: 1) communications with the spacecraft will be maintained throughout the maneuver, and 2) finer control will be achieved over the spacecraft's directional change. The roll-turn technique will be used, if needed, just days before Voyager 2's closest approach to Neptune to fine-tune the aimpoint. In April, three pairs (wind and unwind) of 180° roll turns will be used.

New News about the Neptunian System

The imminent encounter with Neptune has sparked increased Earth-based observations of Neptune's system, and some of the new information is summarized below.



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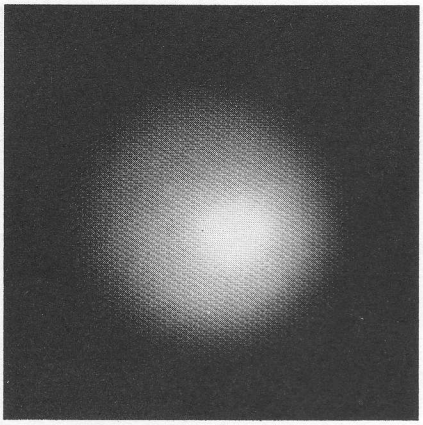

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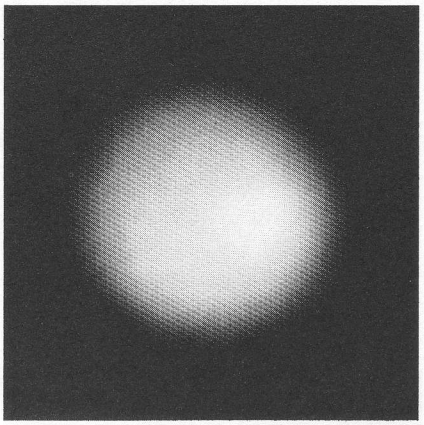

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Neptune

Using the Infrared Telescope Facility (IRTF) at Mauna Kea, Hawaii, Dr. Heidi Hammel of JPL has detected discrete cloud features moving across the disk of Neptune as the planet rotates. These features are clearly visible at 6190 angstroms, the same wavelength as the methane-band filter on Voyager's wide-angle camera. As Voyager 2 gets closer to Neptune, these features should become apparent in Voyager images. Dr. Hammel also reports that clouds at 38° south latitude have a rotation period of 17 hours, while at 30° south latitude the cloud rotation period is 17.7 hours. In addition, she reports a deep haze (down to an atmospheric pressure level of about 100 millibars) at the south pole, and a higher haze (down to about 50 millibars) at the north pole and in the northern hemisphere.

Spectrophotometry observations indicate that Neptune may have a three-layer cloud structure of icy hydrocarbons, a thin methane haze, and a hydrogen sulfide cloud.

Magnetosphere

Using the Very Large Array of antennas in New Mexico, Dr. Imke de Pater of the University of California at Berkeley has detected synchrotron radiation emissions from Neptune. Synchrotron radiation is an indication of the presence of a magnetic field, as charged particles are trapped by a planet's magnetic field and swept around in space by the planet's rotation. Dr. de Pater's calculations indicate that the strength of Neptune's field is 1/2 to 1 gauss. By comparison, the surface field strength of Earth's magnetic field ranges from 0.3 gauss near the equator to 0.7 gauss near the magnetic south pole.

Triton

Estimates of Triton's size are shrinking as some researchers now believe that the largest diameter that Triton could have is about 4,000 km (2,500 mi).

Judging from light reflected by Triton, the satellite's temperature may be about 52 kelvins (K) (about -365°F) for a diameter of 3760 ±780 km (2340 ±480 mi).

Voyager imaging observations indicate that Triton probably is relatively bright and has a somewhat hazy atmosphere, although not as hazy as the atmosphere of Saturn's moon Titan.

Atmospheric pressure models for Triton range from 86 microbars (if the atmosphere is methane only) to 17 millibars (methane and nitrogen). (One bar is the atmospheric pressure of Earth's nitrogen-rich atmosphere at the surface of Earth.)

If Triton's spin axis lies close to Triton's orbital plane instead of perpendicular to it, there may be substantial tidal heating of Triton's surface. (Tidal heating is responsible for the volcanic activity on Jupiter's moon Io.)

There is still controversy and disagreement about Triton's composition. Some laboratory experiments on the spectra of mixtures of liquid nitrogen and methane show a reasonable match to Triton spectra. In this case, solid nitrogen and methane frosts could result in a "solid ocean" of nitrogen 15 to 20 centimeters (6 to 8 inches) deep with methane ice below this.

However, telescopic observations of Triton's spectrum show seven bands of methane and one band attributed to molecular nitrogen, but the physical states—solid, liquid or gas—of these materials are not known. The astronomers who made these observations believe that frozen methane and nitrogen probably exist on the surface, but that the surface may be obscured by a thin haze of photochemical smog similar to that found on Saturn's moon Titan, and more recently, on the planet Pluto.

While water ice was suspected on Triton in data of the early 1980's, newer data do not show it. No evidence for water on Tri-

ton has been seen in photometric data in the 3 to 4 micron range. Triton's spectrum has changed significantly since about 1983 or 1984, perhaps in response to the approach of "maximum summer" (a period when the Sun will shine most directly on the southern hemisphere due to the tilt of the satellite's orbit plus the tilt of Neptune's rotational axis).

If Neptune's magnetosphere is large enough to envelop Triton, then a plasma torus may exist around Neptune, with Triton as the source. Voyager's plasma instrument should be able to detect such a torus if it exists.

Nereid

Nereid has a semimajor axis (the radius of its orbit) of 5,515,000 km, an orbital eccentricity (deviation from perfectly circular) of 0.75, and takes 360.15 days to orbit Neptune. In addition, Nereid's spin axis is tilted 27.6 degrees from perpendicular to Neptune's equatorial plane.

Current estimates of the diameter of Nereid range from 290 to 1060 km (180 to 660 mi). The satellite may be oblong in shape and have a rotation period of 2-1/3 to 4-1/3 days.

A Look at 1989 In Space Exploration

January 29	*Soviet Phobos II Spacecraft enters Mars orbit*
February	*Third Tracking and Data Relay Satellite (TDRS) launches*
April	*Soviet Phobos II lands on Phobos*
April 28	*Magellan Venus radar mapper mission launches*
June 5	*Voyager 2 Neptune Encounter period begins*
August 25	*Voyager 2's closest approach to Neptune*
October 2	*Voyager 2 Neptune Encounter ends*
October 12	*Galileo Jupiter orbiter and probe mission launches*
December 11	*Hubble Space Telescope launches*

Rings?

And finally, the question of Neptunian rings remains open. Out of 110 observed occultations of stars by Neptune, only 8 occultations produced effects that could be attributed to rings or ring arcs near Neptune. Small satellites shepherding ring particles at Neptune could be as small as 10 kilometers (6 miles) in diameter at distances of a few hundred kilometers. And, going far out on a limb, simulations show that polar rings around Neptune would be stable.

Observations and analyses of Neptune continue in support of detailed planning for the Voyager encounter next August.

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Pasadena, California

JPL 410-15-84 1/89

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Voyager

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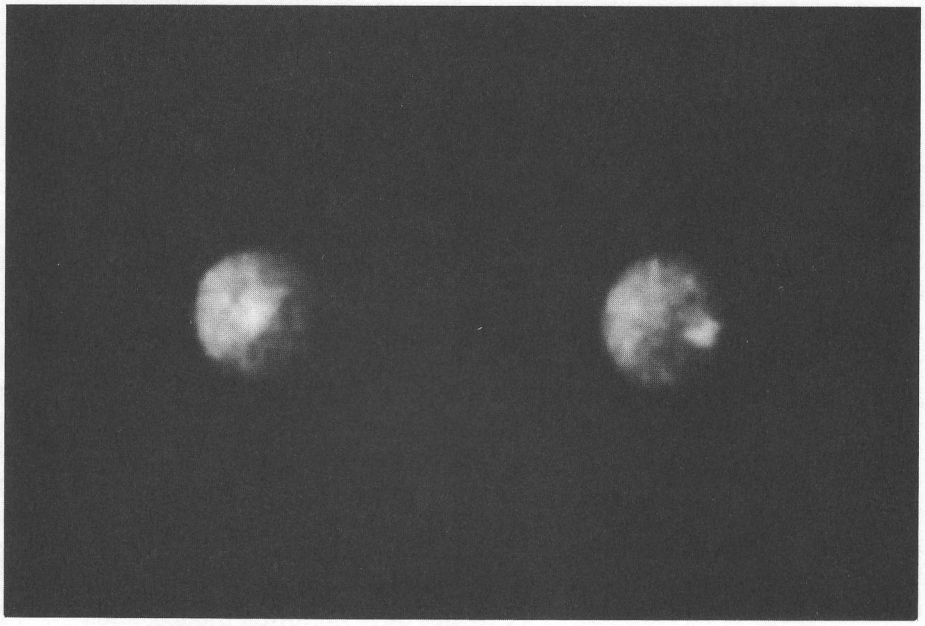
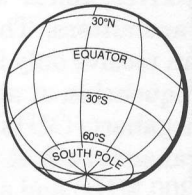
MISSION STATUS REPORT NO. 85 **MARCH 3, 1989**



A bright cloud feature at about 30• south latitude can be seen moving across the face of Neptune in these images taken about two hours apart on January 23, 1989 by Voyager 2. (P-33983)



It's not just a fuzzy tennis ball after all . . .

A bright cloud feature on Neptune, similar to spots seen by planetary astronomers using Earth-based telescopes, is visible in images taken by Voyager 2 on January 23, 1989 when the spacecraft was about 309 million kilometers (185 million miles) from the planet. The fact that distinct cloud features are visible while the spacecraft is still so distant suggests that pictures taken as Voyager 2 approaches its August 1989 flyby of Neptune will show far more detail than was visible in the atmosphere of Uranus, which Voyager 2 encountered in January 1986. (Due to the lack of visible cloud features, Uranus has been lightheartedly described as a "fuzzy blue tennis ball," and less kindly as bland.)

The cloud is at about 30 degrees south latitude, and its motion during the time between images is consistent with the 17- to 18-hour rotation period derived from observations with Earth-based telescopes. The January images show details as small as about 6000 kilometers (3500 miles). The cloud has not yet been confirmed to be any of the cloud features seen on Neptune by Drs. Richard Terrile of JPL and Brad Smith of the University of Arizona at Las Campanas Observatory, Chile, in 1983, or by Dr. Heidi Hammel of JPL at the University of Hawaii's Mauna Kea facility in 1988. The features seen from these Earth-based telescopes were best seen through methane filters not available on Voyager 2, and imaging scientists had been somewhat concerned that such features might not be visible to Voyager 2's cameras.

The mottled appearance of Neptune in these frames is likely to be "noise" in the camera system. Color versions of these images, assembled from

pictures taken through violet, clear, and orange filters, show a dark band of clouds encircling the planet's southern pole (see map). The banded appearance is similar to cloud structures on the three other giant planets, Jupiter, Saturn, and Uranus. The natural color of Neptun is a pale blue-green, caused by the absorption of red light by methane gas in the planet's atmosphere.

Spacecraft Review and Status

Both Voyager spacecraft have survived in space for nearly twelve years, and although each has experienced some hardware failures, they are still in robust health and capable of returning valuable scientific data well into the next century.

Spacecraft Review

The core of each Voyager is a ten-sided bus, an aluminum framework ring which houses the spacecraft's electronics. The bus is about 45 centimeters (1-1/2 feet) high and 180 centimeters (about 6 feet) across.

Each spacecraft carries three computer subsystems: the computer command subsystem (CCS), the flight data subsystem (FDS), and the attitude and articulation control subsystem (AACS). Each computer has a backup, for a total of six computers, each with a separate memory.

The CCS is in overall control of the spacecraft. It monitors spacecraft activities, routes commands back and forth between the other computers, receives commands from Earth, and issues commands to send data back to Earth.

Computer programs (called sequence loads) to control the spacecraft are written on Earth and transmitted to the CCS. During cruise phases, a sequence load may operate the spacecraft for as long as six months; during a planetary encounter, a sequence load may operate the spacecraft for as few as 50 hours, depending on the complexity of the activities required to obtain the science data at the planet. A sequence load for a relatively quiet cruise phase may take about nine weeks to plan, build, and test before it is sent to the spacecraft, while an encounter load may take as long as 15 months.

Seven fault detection and correction routines are stored in the CCS at all times to automatically place the spacecraft in a safe state should the CCS detect a problem, such as an electrical short, a receiver or transmitter failure, or a failure in the CCS.

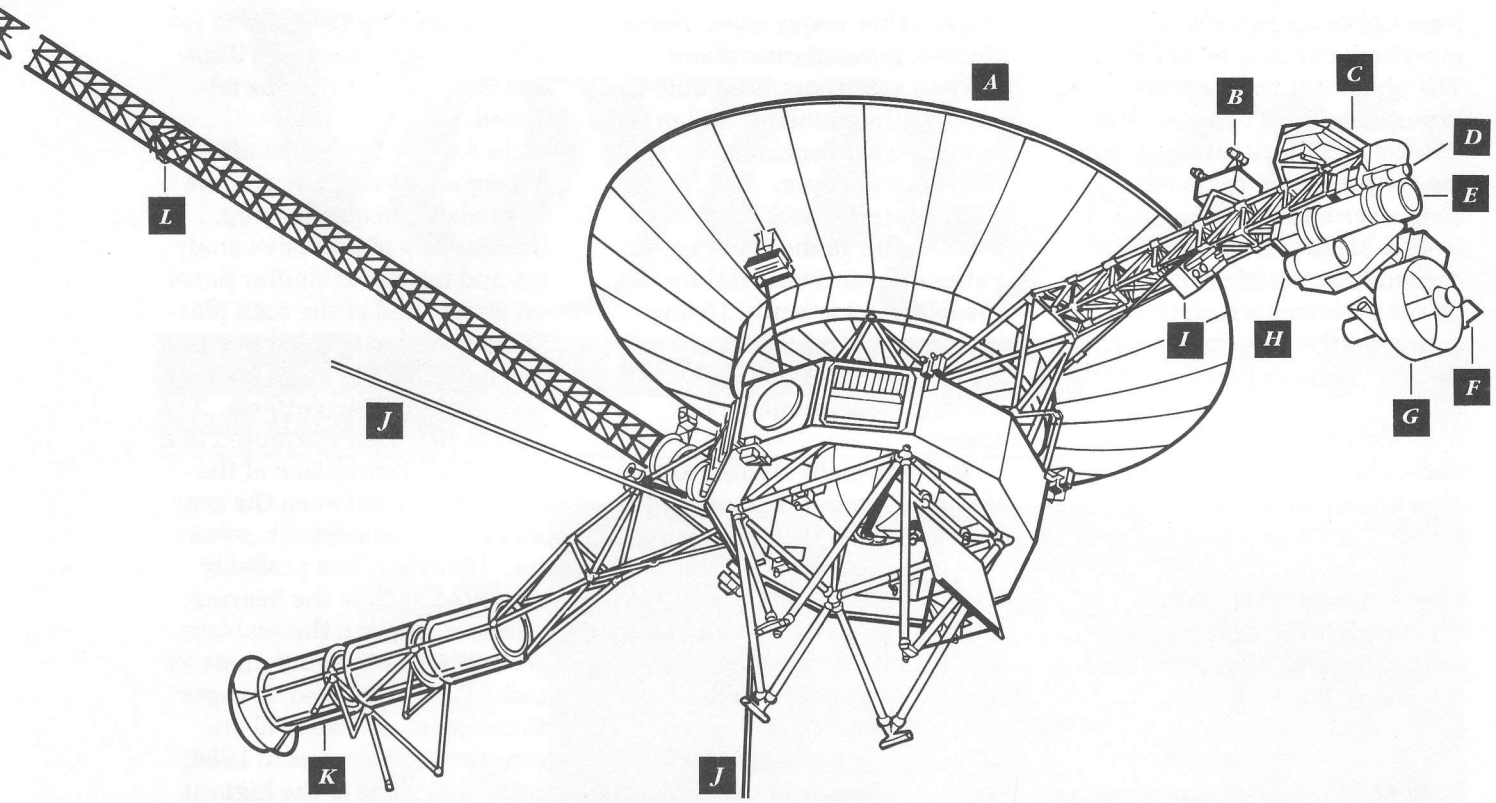
The FDS collects engineering and science data measurements and formats the data for transmission to Earth. The FDS controls the science instruments as directed by the CCS. The FDS also has several special data handling modes, such as data compression and encoding.

Data is often recorded on board the spacecraft on a high-capacity eight-track digital tape recorder for transmission to Earth at a later, more convenient time. For example, mission controllers may opt to wait until the spacecraft is "over" a specific DSN station before asking the spacecraft to transmit its data to Earth. Similarly, data is recorded during high-activity periods, or when the spacecraft is behind a planet.

The AACS maintains the pointing of the spacecraft's antenna, orients or maneuvers the spacecraft, and points (articulates) the scan platform. The spacecraft is stabilized on three axes (pitch, yaw, and roll) and senses its orientation either through its internal gyroscopes, or by tracking two celestial bodies (typically the Sun and a reference star such as Canopus). The AACS maintains the spacecraft's orientation by using small rocket thrusters which expel hydrazine propellant, a compound of nitrogen and hydrogen. At launch, each spacecraft carried about 105 kilograms (232 pounds) of hydrazine. During its 11-1/2 years in space, Voyager 2 has used about 60 kilograms (140 pounds) of hydrazine.

The Voyagers communicate with Earth via their telecommunications systems, which include a 3.65-meter (12-foot) diameter high-gain antenna, a low-gain antenna, an S-band receiver, and X- and S-band transmitters. The spacecraft can receive only in the S-band frequencies, at about 2100 megahertz (MHz). They can transmit both at S-band (about 2300 MHz) and at X-band (about 8400 MHz). (By comparison, typical FM radio transmission is at about 100 MHz, while AM radio transmissions range from about 50 to 160 kilohertz). The X-band frequency has a narrower beamwidth and thus a tighter focus than does the S-band. The wavelength of the X-band signal is 3.5 centimeters (less than 1.5 inches), while the wavelength of the S-band signal is slightly longer at 13 centimeters (about 5 inches).

Each Voyager is powered by three radioisotope thermoelectric generators (RTGs), which produce electrical energy through the conversion of heat generated by the radioactive decay of plutonium-238. At launch, the power output of the



A	*High-Gain Antenna*	E	*Imaging, Narrow-Angle*	I	*Low-Energy Charged Particles Detector*
B	*Cosmic Ray Detector*	F	*Ultraviolet Spectrometer*	J	*Planetary Radio Astronomy and Plasma Wave Antennas (2)*
C	*Plasma Detector*	G	*Infrared Spectrometer and Radiometer*	K	*Radioisotope Thermoelectric Generators (3)*
D	*Imaging, Wide-Angle*	H	*Photopolarimeter*	L	*Magnetometer (1 of 4)*

RTGs was about 423 watts. The power output steadily declines as the plutonium decays, and is now about 380 watts. The science instruments require about 105 watts, or about the same wattage as a typical light bulb.

Instruments Description and Health

Each spacecraft carries instruments for ten scientific investigations. Optical instruments for four of the investigations are mounted on a movable (scan) platform at the end of a short boom. Instruments for six more investigations measure magnetic and electrical fields and charged or neutral particles in space and in the vicinity of planets. In addition, the spacecraft's radio is used for an eleventh investigation.

Scan Platform Instruments

Imaging Cameras (ISS): Each Voyager spacecraft carries two imaging cameras: a 200-mm, f/3.5 wide-angle camera using a refracting telescope and a 1500-mm f/8.5 narrow-angle (telephoto) camera using a reflecting telescope. Each camera uses a one-inch selenium-sulfur vidicon to convert an optical scene into electrical signals. Each frame consists of 640,000 picture elements (pixels), each of which is expressed as a level of grey on a scale from 0 (black) to 255 (white). Color scenes are reconstructed on Earth by electronically combining images taken through different filters. The sensitivity of the filters ranges from 3460 (ultraviolet) to 6184 angstroms (red-orange). (The human eye can see in the range from 3800 to 6800 angstroms.)

Voyager 2's narrow-angle camera has dust specks on the vidicon which result in faint, doughnut-shaped blemishes in images. In addition, the emission of the vidicon cathode in the narrow-angle camera has decreased since launch.

Imaging team leader is Dr. Bradford A. Smith of the University of Arizona, Tucson, Arizona; deputy team leader is Dr. Larry A. Soderblom of the U.S. Geological Survey, Flagstaff, Arizona.

Photopolarimeter (PPS): The photopolarimeter measures the way light is scattered from particles in an atmosphere or on a surface. By studying the polarization of reflected light as the lighting geometry changes during a flyby, scientists can make inferences about the nature of a planetary surface or atmosphere. The photopolarimeter can also be used to study rings by measuring the intensity of a background star as the starlight passes through the rings.

The photopolarimeter consists of a 200-mm Cassegrain telescope with filters, polarization analyzers, and a photomultiplier tube to convert incoming light into electronic signals. It covers three wavelengths in the region between 265 and 750 millimicrons. Five of the eight original filters and four of the eight original analyzers are no longer accessible.

Principal investigator is Dr. Lonne Lane of the Jet Propulsion Laboratory, Pasadena, California.

Infrared interferometer spectrometer and radiometer (IRIS): IRIS measures the temperatures of planets and satellites to determine their energy balance (the balance between the heat received from the Sun and the heat—if any—generated by the body itself). Global temperature maps are produced for each body. IRIS also studies the molecular composition of atmospheres, and can detect molecules such as hydrogen, ammonia, methane, ethane, acetylene, and other complex hydrocarbons. IRIS uses a 50-cm telescope to gather light and direct it into the optics. The radiometer measures the solar radiation reflected from a body in the range from 0.3 to 2.0 microns, while the interferometer measures radiation emitted in the middle- and far-infrared (4.0 to 55 microns). The neon reference signal has decreased, and the interferometer has lost some of its sensitivity due to degraded alignment of its optical components.

Principal investigator is Dr. Barney J. Conrath of NASA's Goddard Space Flight Center in Greenbelt, Maryland.

Ultraviolet spectrometer (UVS): The ultraviolet spectrometer studies the chemical composition, temperature, and structure of atmospheres by observing how ultraviolet light from the Sun is absorbed or scattered after it enters the atmosphere of a planet or satellite. It also studies ultraviolet light coming from stars.

The UVS detects and measures ultraviolet radiation in the range from 500 to 1700 angstroms. Included in this range are the atomic hydrogen Lyman alpha series, molecular hydrogen, helium, methane (natural gas), acetylene, ethane, and other atmospheric hydrocarbons.

Principal investigator is Dr. A. Lyle Broadfoot of the University of Arizona, Tucson, Arizona.

Radio Science

Effects on Voyager's radio signals can help determine the structure and composition of an atmosphere, the size and distribution of particles in rings, and the characteristics of planetary

and satellite gravitational fields.

Team leader is Dr. Len Tyler of Stanford University's Center for Radar Astronomy, Stanford, California.

Fields & Particles Instruments

Magnetometers (MAG): Each Voyager carries four magnetometers mounted along a 13-meter (43-foot) boom. The magnetometers help characterize planetary magnetic fields, as well as the structure of a magnetosphere and its interactions with planetary moons. Interplanetary magnetic fields are also measured.

The dynamic range of the low-field magnetometers is from about 0 to 50,000 gammas, while the range of the high-field magnetometers is from about 1/2 to 20 gauss (50,000 to 2 million gammas).

Principal investigator is Dr. Norman F. Ness of the University of Delaware's Bartol Research Institute, Newark, Delaware.

Plasma (PLS): Plasmas are hot ionized gases that flow like liquids and are affected by magnetic fields. Plasmas are often trapped by planetary magnetic fields and interact with planetary satellites and rings. The plasma detector characterizes these interactions and also determines the properties and radial evolution of the solar wind. PWS measures protons and electrons in the energy range from 10 to 5950 volts and ions from 20 to 11,900 volts.

Principal investigator is Dr. John W. Belcher of the Massachusetts Institute of Technology's Center for Space Research, Cambridge, Massachusetts.

Low-Energy Charged Particles (LECP): The LECP instrument measures the composition and energy spectrum of low-energy charged particles trapped in planetary magnetospheres, as well as the distribution and variation of galactic cosmic rays. The instrument measures electrons in the range from about 15,000 volts (15 keV) to more than 11 MeV, and protons and heavier ions in the range from 20 keV to 150 MeV, as well as nuclei in the range from about 47 keV to more than 200 MeV per nucleon. The sensitivity of the LECP has decreased slightly over the years.

Principal investigator is Dr. S. M. (Tom) Krimigis of the Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland.

Cosmic Rays (CRS): Cosmic rays are the most energetic particles found in nature and are atomic nuclei (primarily protons) and electrons. Voyager's cosmic ray package uses seven telescopes to analyze cosmic-ray nuclei ranging from hydrogen through iron, over an energy range from about 1 to 500 MeV. Principal investigator is Dr. Edward C. Stone of the California Institute of Technology, Pasadena, California.

Planetary Radio Astronomy (PRA): Radio emissions from planets are generated by charged particles spiraling along magnetic field lines. Since the magnetic field originates in the interior of a planet, the radio emissions are a good indication of processes within the planet. Radio emissions from the Sun and

from lightning in a planet's atmosphere can also be detected. The planetary radio astronomy experiment uses two 10-meter (33-foot) whip antennas to listen for planetary radio emissions over a range from 1.2 kHz to 40.5 MHz. The PRA has occasional, seemingly random power problems which the spacecraft is now programmed to sense and automatically correct.

Principal investigator is Dr. James W. Warwick of Radiophysics, Inc., Boulder, Colorado.

Plasma Waves (PWS): Plasma waves are low-frequency oscillations in the plasmas in interplanetary space and in planetary magnetospheres. The plasma wave instrument detects and measures plasma wave interactions in planetary magnetospheres and detects interactions between a planetary magnetosphere and the solar wind. It can detect particles in the ring plane and measure their impact rate on the spacecraft. The PWS shares the two whip antennas with the PRA investigation to provide the equivalent of a single 7-meter antenna. PWS covers the frequency range from 10 Hz to 56.2 kHz.

Principal investigator is Dr. Donald Gurnett of the University of Iowa, Iowa City, Iowa.

Voyager 2's Health

Both Voyagers have experienced several health problems since launch, some minor and some rather major ones. Nonetheless, mission controllers have in every case been able to identify the problems and provide a way to continue to meet mission objectives.

In September 1977, about a month after launch, Voyager 2 suffered a hardware failure in the FDS. As a result, 15 engineering measurements can no longer be made (about 215 engineering measurements remain).

In 1978, eight months after launch, Voyager 2's main radio receiver failed, and a tracking loop capacitor failed in the backup receiver. As a result, Voyager 2 can receive signals in only a narrow "window" of frequencies—and the window slides. The window is about 1000 times narrower than it originally was, and temperature changes in the radio receiver of even 1/4° cause the window to slide up or down in frequency. Temperature changes can be caused by heat generated by the spacecraft's electronics. The flight team has devised a rigorous routine for commanding the spacecraft. Signals are sent several times at different frequencies to determine the receiver's current frequency "window". Commands are then transmitted, after calculating where the receiver's "window" will be, and taking into account how the signal frequency will change due to the Earth's rotation and other motions.

The receiver problem occurred nearly a year before Voyager 2 reached its first objective, the Jupiter system, yet successful encounters of Jupiter, Saturn, and Uranus followed.

In August 1981, just after Voyager 2 passed Saturn, the scan platform quit moving. Three years of intensive analysis and testing of similar parts on Earth, and of the scan platform on Voyager 1, led to a failure model and to guidelines for safe usage of the platform. The failure has been attributed to a lack of full lubrication of the bearing area between the gear and pin in the azimuth actuator. Lubricant has probably migrated back to the bearing surfaces, healing the problem. Adherence to the guidelines for safe usage permitted Voyager to complete a successful encounter with Uranus in 1986, returning some of the highest resolution images ever taken of solar system bodies. The scan platform was programmed to track the target body during certain exposures.

The Uranus encounter was not without its surprises, either. Just days before its closest approach to Uranus, Voyager 2 suffered the loss of one word of memory in one FDS processor. As a result, bright and dark streaks appeared in images. Only imaging data was affected, and a software patch was sent to bypass the failed bit.

Despite a little arthritis, a little hearing problem, and some loss of memory, Voyager 2 is still in excellent operating condition, and gaining rapidly on Neptune and Triton.

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JPL 410-15-85 3/89

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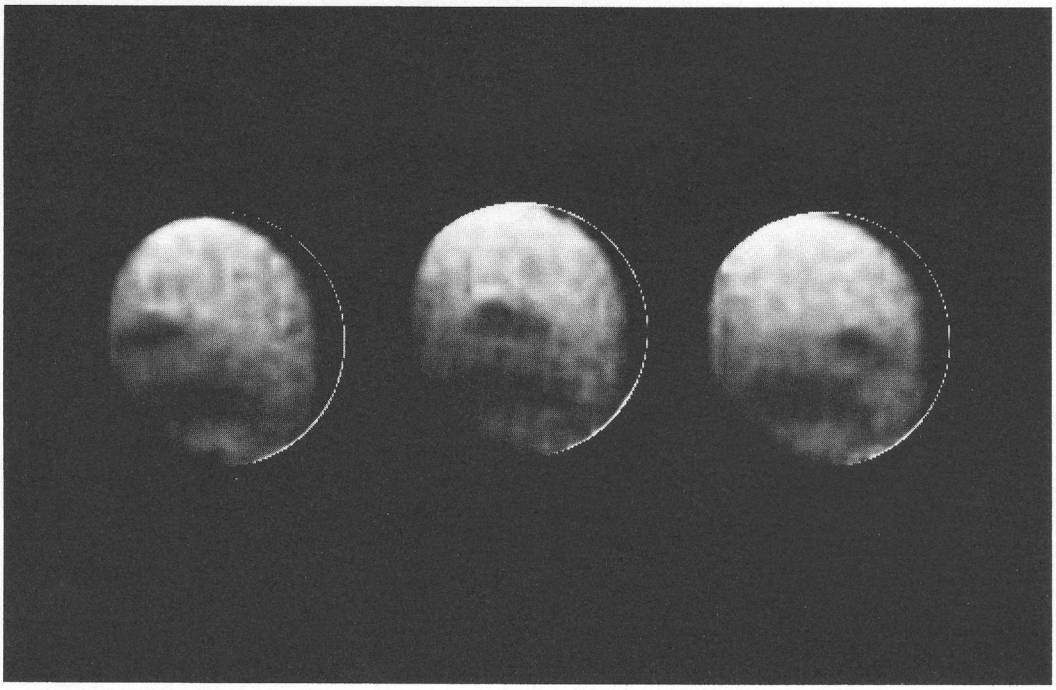
MISSION STATUS REPORT NO. 86 **APRIL 19, 1989**



A dark band encircles Neptune's south pole, while a large dark spot in the southern hemisphere rotates around the planet with a period between 17 and 18 hours.
(P-34192)

Does Neptune have a Great Spot?

A large dark spot and a dark band encircling the south polar region of Neptune are visible in images acquired 90 minutes apart by Voyager 2 on April 3, 1989, from a distance of 208 million kilometers (129 million miles). The spot rotates around the planet in 17 to 18 hours.

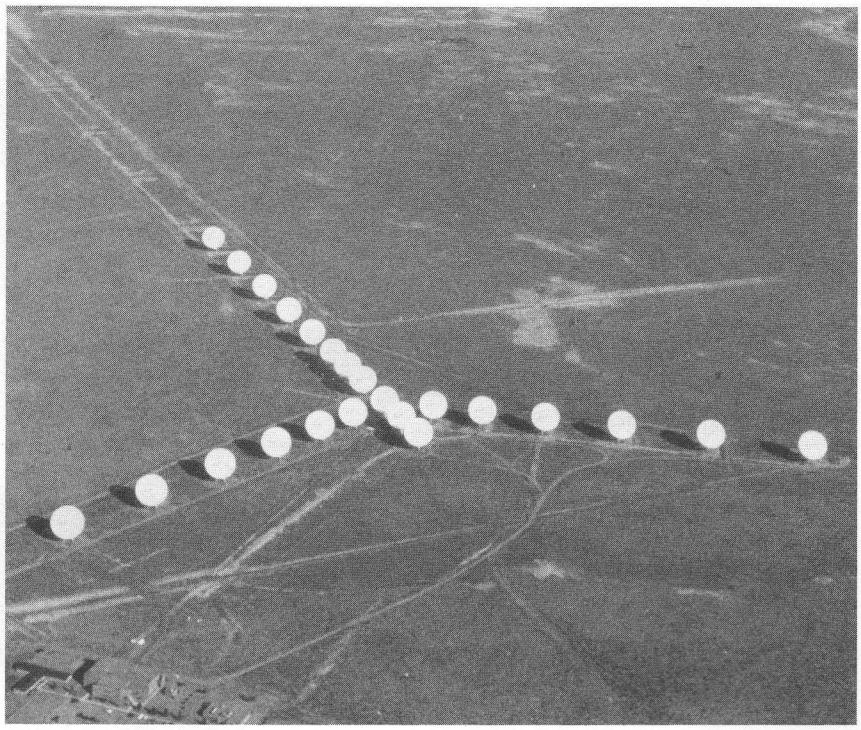
Detection of the spot will allow atmospheric scientists to determine rotation rates of features in the planet's atmosphere much earlier than had been expected. Voyager 2's cameras will track cloud features over the next several months.

The spot extends from 20 degrees south to 30 degrees south latitude, and spans 35 degrees in longitude. Relative to the size of Neptune, the dimensions of the spot are comparable to Jupiter's Great Red Spot.

The images were taken through the narrow-angle camera's clear filter, which is most sensitive to blue light. The spot is 10 percent darker than its surroundings. The smallest object that can be seen in these images is about 3850 kilometers (2400 miles) across.

Scientists have not yet determined whether this is the same spot seen in images taken 70 days earlier in late January. The spot seen in the January images appears dark through the clear filter but bright through the orange filter. Features seen through the orange filter may be at higher altitudes than those visible in these most recent images.

The jagged white rim on the right edges of the images are processing artifacts.



The antennas of the Y-shaped Very Large Array spread across the plains in central New Mexico.
(JPL 2816A)

Very Large Array

For Voyager's Neptune encounter this summer, a new data-acquisition partnership has been forged with the Very Large Array (VLA), a unique radio astronomy instrument in west-central New Mexico.

As spacecraft travel farther from Earth, the strength of the signal received at Earth weakens, primarily due to the great distance traveled* . By the time Voyager 2's signals from Neptune (about 4.5 billion kilometers away) reach Earth, they will be less than half as strong as those received from Voyager 2 from Uranus (about 3 billion kilometers from Earth) in 1986.

The telemetry data rate would be reduced by the same amount if improvements had not been made in the data acquisition facilities on Earth.

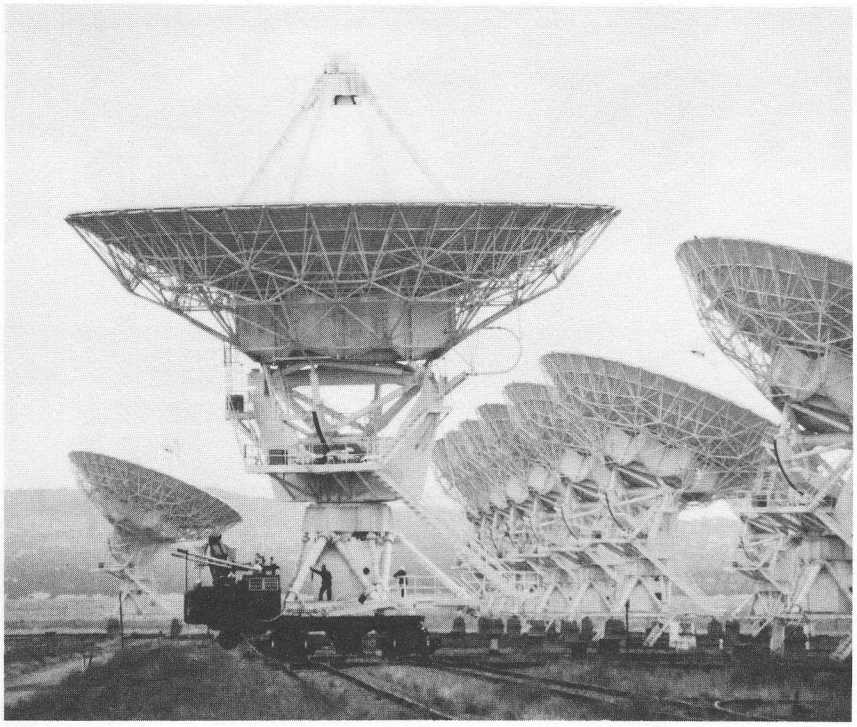
To capture Voyager 2's data from Neptune, NASA's Deep Space Network (DSN) has upgraded their three 64-meter antennas to 70 meters and made them more efficient, built a new high-efficiency 34-meter antenna at the Madrid complex, combined signals from several antennas, and added non-DSN antennas to the system.

The technique of combining the weak signals received at several antennas into a single, stronger signal is known as arraying. During Voyager's Saturn encounters in 1980 and 1981, adjacent 64-meter (210-foot) and 26-meter (85-foot) antennas at DSN sites were successfully arrayed. The technique was extended during the Uranus encounter in 1986, when the Canberra Deep Space Complex was arrayed with the Australian government's Parkes Radio Observatory antenna 275 kilometers (170 miles) away. For Neptune, Parkes and Canberra will once again be arrayed, and the VLA will be arrayed with the DSN antennas at Goldstone, in California's Mojave Desert.

The VLA, a complex of twenty-seven 25-meter (82-foot) antennas (plus a spare), is a part of the National Radio Astronomy Observatory (NRAO) operated by Associated Universities, Inc., under a cooperative agreement with the National Science Foundation. The VLA will track Voyager 2's signal this summer and send the raw data via satellite to Goldstone. There, the signals from VLA will be electronically combined with Voyager signals received by Goldstone's antenna array (at least one 70-meter [230-foot] and one or two 34-meter [111.5-foot] antennas). Use of the VLA will add the equivalent of about one and a half 70-meter antennas to the Network.

The Voyager partnership with NRAO–VLA started in 1982 when it was recognized that should Voyager 2 survive to fly past Neptune, greater receiving capability was required. An interagency Memorandum of Understanding between NASA and the National Science Foundation was signed in 1984.

*A formula known as the inverse-square law is used to estimate the decrease in signal strength: radio signals weaken according to the ratio of the squares of the distances from the transmitter to the receiver. At the time of Uranus flyby in 1986, for example, Uranus was at about 19 AU (an astronomical unit (AU) is the average distance from the Sun to the Earth, about 150 million kilometers or 93 million miles), while Neptune will be at 30 AU. Therefore, $19^2/30^2 = 361/900 = 0.4$. In other words, the signals received from Voyager 2 at Neptune will be about 40 percent as strong as those that were received from Uranus.



The 230-ton antennas are moved to different foundations by transporter vehicles traveling over 40 miles of railroad tracks.
(JPL 3763)

All that remained was to await the Congressional go-ahead for Voyager 2 to be sent on to Neptune. The Neptune mission was approved in 1985.

The arraying techniques and upgrades to the DSN antennas mean that the Network will be able to reliably capture a maximum data rate from Voyager at Neptune of 21,600 bits per second (bps), about the same as the DSN could capture during the Uranus encounter in 1986. Without these improvements in the ground facilities, the maximum data rate would have been 14,400 bps and only for brief periods each day. (In 1965, Mariner 4's date rate from Mars [at 1.5 AU] was only 8-1/3 bits per second.)

What is the VLA?

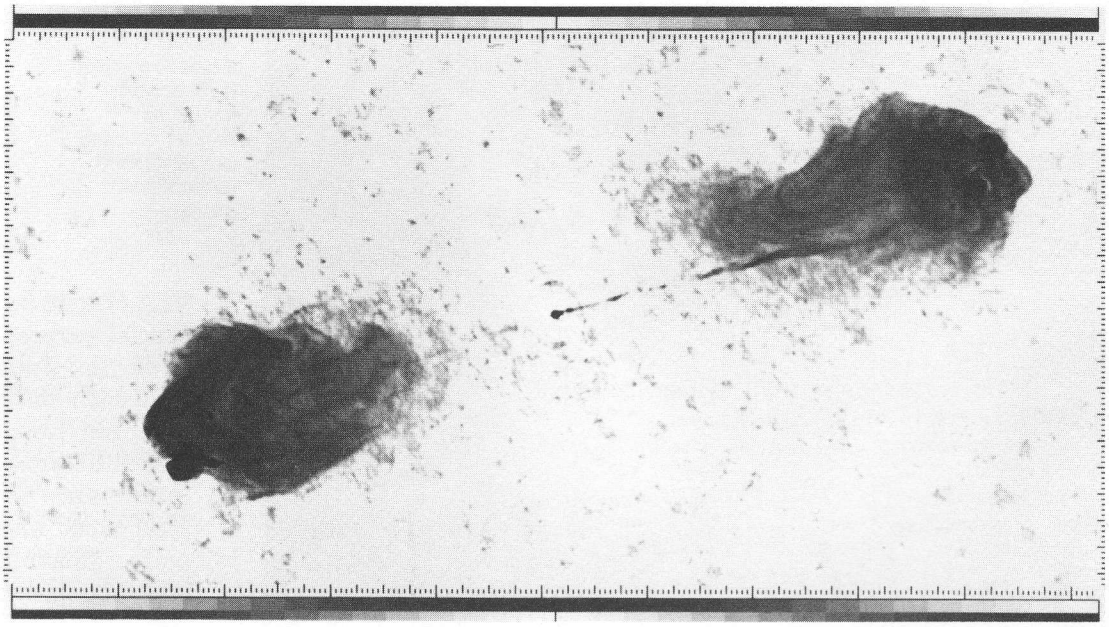
The VLA is a radio astronomy instrument that is used to detect and map fine detail in distant radio sources to gain a better understanding of the physical processes involved in distant galaxies that emit radio radiation. The VLA makes images using radio waves, whose nature is similar to light but whose wavelength is many thousand times longer and thus cannot be seen by the human eye.

Strong emitters of radio radiation, such as "radio" galaxies, emit between a thousand and a million times more radio radiation than other galaxies do. Radio astronomers use instruments such as the VLA, with its great sensitivity and resolving power (the ability to distinguish between two objects very close to each other), to investigate the nature of the processes occurring in radio galaxies.

The VLA consists of 27 dish-shaped antennas arranged in a Y-shape spreading across the Plains of St. Augustin about 50 miles west of Socorro, New Mexico. The captured signals are electronically combined (arrayed) to effectively form a single large radio telescope. The combining is done in the VLA control center, where a special purpose computer compares (multiplies) the signal from each antenna with every other antenna, calculating the time difference and signal interference for each pair, for a total of 351 interferometer pairs. This multiplication is done 100 million times a second.

Each 230-ton antenna can be moved to different foundations on the "Y" by transporter vehicles riding on railroad tracks. Four basic configurations are used, ranging from clustering the antennas to within 0.6 kilometer (2000 feet) of the center of the array, to stretching them out so that the most distant antenna is 21 kilometers (13 miles) from the center. To track Voyager 2, the antennas will be positioned near the center of the array, but slightly modified in spacing so that the south-facing antennas won't shadow each other.

The antennas are physically connected by underground waveguides—tubes through which electronic signals travel from the antennas to the control center. At regular intervals, the wave flow is reversed to send control signals from the control center to the antennas, briefly interrupting the data flow. The architecture of Voyager's Reed-Solomon data encoding system on board the spacecraft largely overcomes any degradation in these intervals after the signals from the VLA and Goldstone are combined at Goldstone.



The VLA is a radio astronomy instrument that is usually used to study objects such as the radio galaxy Cygnus A, rather than interplanetary spacecraft. (Courtesy NRAO/AUI) (Acknowledgment: R.A. Perley, J.W. Dreher, and J.J. Cowan)

Upgrades to the VLA

To be able to support Voyager, the VLA site needed a number of upgrades. First, all of the antennas were fitted with new receivers able to capture Voyager's X-band signals (about 8.4 gigahertz, or 8.4 billion cycles per second). These receivers include low-noise amplifiers which are helium-cooled to temperatures of about 15 kelvins (-430°F) to reduce internally generated noise which tends to mask the very weak radio signals from space. The amplifiers use state-of-the-art devices called high-electron mobility transistors (HEMTs) which allow a faster flow of electrons across the layers of the semiconductor but create less heat. The HEMTs are credited with improving the performance of the system beyond what had been initially planned. The upgrade to X-band receivers took about four years, done over the VLA's normal maintenance cycle. The new VLA capability at X-band will be used for other science such as planetary radar, very-long-baseline interferometry, imaging continuum emissions, and imaging spectral-line emissions and absorptions.

JPL has also provided new signal-processing equipment similar to that implemented in Australia for the Canberra/Parkes array.

A study of the VLA power system, consisting of power purchased from the overhead grid of the local electric utility company, showed that the system was vulnerable to voltage transients and outages due to severe wind and lightning storms, for example. To minimize the risk of losing any of the irreplaceable first images from Neptune, the VLA has been equipped with two diesel generators, each rated to deliver 1400 kilowatts, to assure a steady supply of reliable, high-quality power during Voyager tracking periods. Although one generator alone is capable of supplying the total power required, the two generators will operate in parallel, each loaded at 50 percent of their rating.

Data from the VLA will be routed to Goldstone via a microwave link using a geosynchronous satellite. At Goldstone, the signals received at VLA and at Goldstone will be combined. The data will be recorded at both sites to prevent loss of data should the satellite link fail.

In addition to the hardware and software upgrades, three DSN operators will be located at the VLA to coordinate and monitor the operation of the VLA–Goldstone Telemetry Array.

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JPL 410-15-86 4/89

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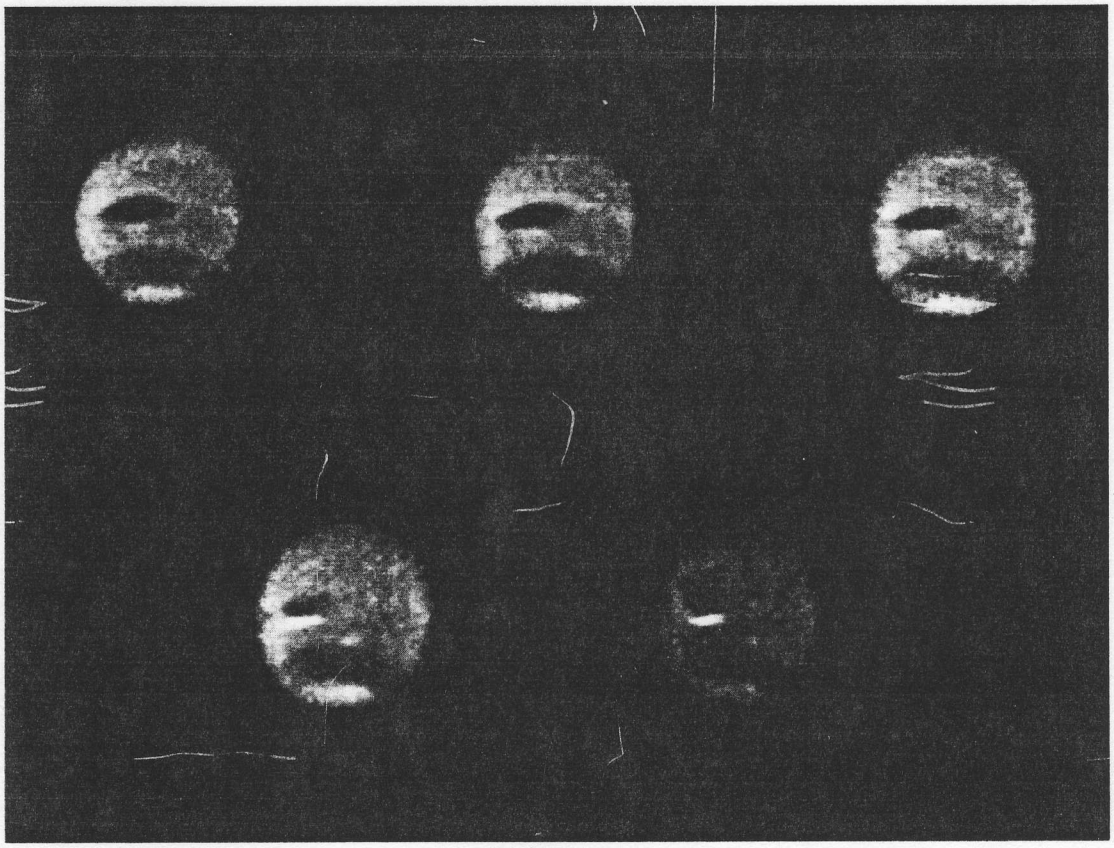
MISSION STATUS REPORT NO. 87 JUNE 15, 1989



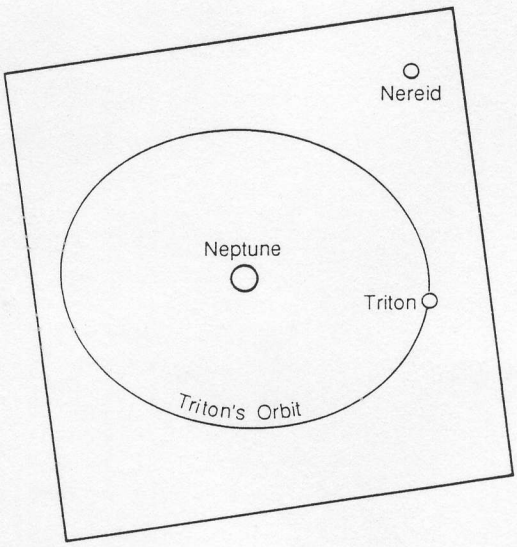
Neptune's appearance differs markedly in images taken through colored filters. (Top row: violet, blue, unfiltered. Bottom row: green, orange). (P-34322)

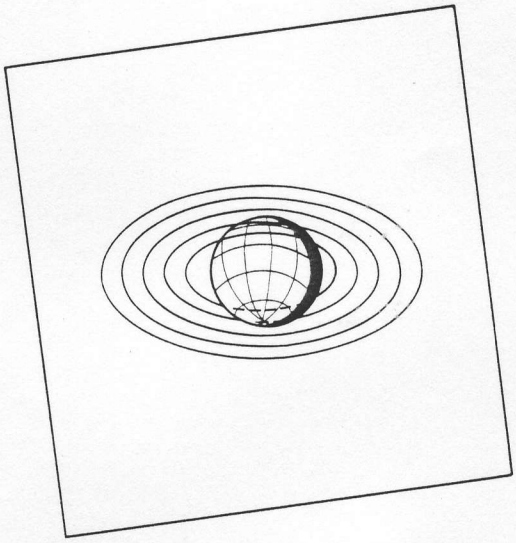
Dynamic Neptune

Three months before Voyager 2's closest approach to Neptune, the spacecraft is returning images of the planet that show an unexpectedly dynamic atmosphere on the eighth planet from the Sun. A recently released set of five images, taken on May 24 when the spacecraft was 134 million kilometers (83 million miles) from the planet, shows the large dark spot, smaller white spot, atmospheric banding, and brightening at the south pole seen in earlier images. The images were taken through five different filters on Voyager 2's narrow-angle camera. The planet's appearance differs markedly as it is photographed in different colors, probably because of differences in colors of specific cloud features and the effects of hazes. Bright features are more visible in green and orange light, while darker features show more contrast in violet and blue light. The degree of dynamic activity was unexpected in Neptune's atmosphere because Neptune receives only one-tenth of one percent as much solar energy as does Earth.

Observatory Phase Begins

The 62-day Observatory phase of the Neptune encounter began on June 5 and will continue until the Far Encounter phase begins on August 6. Three command loads will operate Voyager 2 during the Observatory period. Tracking coverage will be increased to 24 hours a day, and Voyager 2 will begin repetitious observations of the Neptune system, including ultraviolet scans to search for neutral hydrogen and excited ions. The imaging cameras will be trained on the planet to study atmospheric dynamics as Voyager 2 approaches Neptune. In addition, engineering calibrations and checks will be performed. On June 8, engineers performed a test to monitor the performance of the azimuth actuator on the scan platform. On June 12, the antenna and sun sensor were calibrated. On June 15, the spacecraft will perform four yaw turns and four roll turns to calibrate the magnetometer sensors and will then calibrate the alignment of the boom on which the sensors are mounted. A radio science operational readiness test will be conducted on June 28, and a trajectory correction will take place on August 1.





From the first image of the Observatory phase to the last, Neptune will steadily grow in the field of view (7.5 x 7.5 milliradians) of Voyager 2's narrow-angle camera.

Soviet Scientists Named to Voyager Teams

Three Soviet scientists have been invited to become Voyager Interdisciplinary Scientists. The scientists, their institutions, and their areas of expertise are: Dr. Alexandre T. Bazilovski, Vernadsky Institute for Cosmochemistry, Moscow, (solid surfaces); Dr. Vladimir A. Krasnopolsky, Institute for Space Research, (atmospheres); and Dr. Lev M. Zelenyi, Institute for Space Research, (magnetospheres).

The three scientists will spend about a month at JPL, centered around Voyager 2's close approach to Neptune in August 1989.

The participation of Interdisciplinary Scientists in planetary programs is not limited to their recognized areas of scientific expertise. They share equally in the scientific and supporting data needed to carry out their scientific studies, have rights of authorship on published papers to which they contribute, and are bound by established policies regarding individual publications and proprietary rights to data. (By contract, NASA-funded scientists have proprietary rights to their data for one year after its receipt.)

The Soviet scientists' involvement grew out of the U.S./U.S.S.R. Joint Working Group on Solar System Exploration, which has worked out agreements for cross-participation in U.S. and Soviet solar system exploration programs.

The Voyager science teams include about 150 scientists from the U.S., Canada, Great Britain, France, West Germany, and Italy who work on Voyager's eleven scientific investigations.

Near Encounter Test Completed

With the successful completion of the Near-Encounter Test (NET) on May 24-25, the Voyager Flight Team has completed its test and training period and is ready to begin the Neptune encounter, which officially started on June 5, 1989, 81 days before Voyager 2's closest approach to Neptune.

According to Doug Griffith, Voyager Encounter Preparations Manager, the NET was "99 percent like the real encounter" in terms of what the spacecraft was doing.

"The NET was a high-fidelity execution of the most active 12 hours of sequences on the spacecraft," he explained. The NET was a slice of the 53-hour Near Encounter phase, during which the highest value science will be gathered next August 24-25.

Tracking support was provided by the Very Large Array/ Goldstone Telemetry Array in North America, the Parkes/Canberra Telemetry Array in Australia, and the Usuda tracking station in Japan. (Because Voyager 2 is in the southern hemisphere as seen from Earth, the highest value encounter data will be received when the spacecraft is "over" Australia.)

For the NET, Voyager 2 was programmed to perform all spacecraft motions that could be performed without pointing sensitive instruments toward the bright Sun, including five of eight medium-rate (0.33 degrees/second) slews of the platform on which the optical instruments are mounted, image motion compensation, nodding image motion compensation, maneuverless image motion compensation, spacecraft roll maneuvers to new reference stars, and the radio science limbtracking maneuver. The limbtracking maneuver in the NET was part of a radio science operational readiness test.

"All objectives of the NET were met with the exception of some problems in obtaining all the ground-based radio science data. These objectives will be retested in late June and early August," Mr. Griffith summarized.

NASA Select TV to Feature Voyager 2 Neptune Images

Beginning Tuesday, June 13, at noon EDT, a selection from the previous week's images of Neptune from the Voyager 2 spacecraft will be broadcast on the NASA Select TV system, which uses Satcom F2R, transponder 13, every Tuesday through August 8. NASA Select TV is available only in the contiguous United States since the Satcom satellite is in geosynchronous orbit over North America.

The broadcast of the images is expected to last about 1 hour and will show a replay of the first-order reconstruction of Voyager 2's imaging system views of Neptune. At the time of the first image in the first broadcast, Voyager 2 was nearly 2-2/3 billion miles from Earth and approximately 71 million miles from Neptune.

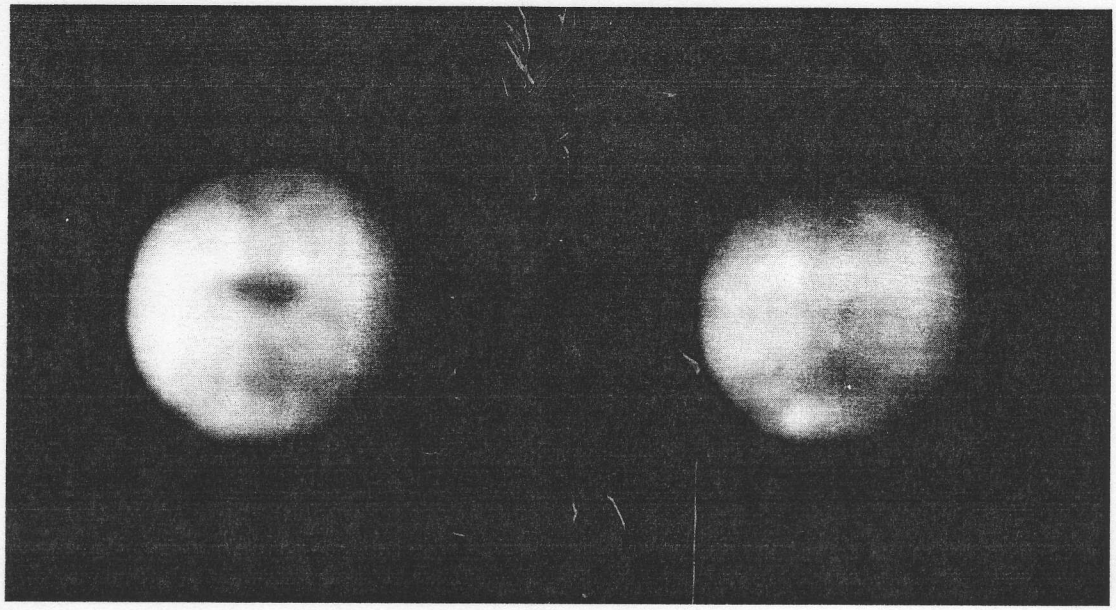
On June 5, the Voyager 2 spacecraft went into the Observatory phase mode. In this mode the spacecraft begins a series of imaging observations of Neptune from afar. Five images are taken every 3 hours, 34.4 minutes (one-fifth of Neptune's estimated rotation period). Voyager planetary scientists will use these images to help study the Neptune atmosphere, already seen to be more turbulent than that of Uranus and possessing what appear to be variable "white" spots, covering portions of whole hemispheres. The spots come and go with relative rapidity. Dr. Brad Smith, University of Arizona, said, "Neptune is now more interesting than Uranus was even at close encounter." Dr. Smith is the Voyager Imaging Team leader.

The timetable for NASA Select replay of Voyager 2 images, along with the distance remaining to Neptune and the distance from Earth, is given below.

The images to be replayed on NASA Select will include both

Broadcast Date	Voyager's 2 Distance at Start of Each Broadcast to Neptune (million miles)	from Earth (billion miles)
June 13	70.70	2.65
June 20	64.40	2.65
June 27	59.00	2.66
July 4*	53.73	2.66
July 11	48.30	2.66
July 18	42.88	2.67
July 25	37.45	2.68
August 1	32.03	2.69
August 8	26.60	2.70

*This date may move later in the week due to holiday observance.



A white spot (seen in right image) near Neptune's south pole was only faintly visible in images taken only 18 hours earlier. These two images were taken about five hours (100 degrees longitude) apart on April 26, 1989. (P-34255)

the actual image of Neptune as seen by Voyager and engineering and science information about the conditions of the imaging system and lighting. This data will appear alongside each image of retransmissions but will be removed in later, more processed views. Early transmissions will not show a great amount of detail and the planet will occupy only a small portion of the imaging frame. Detail will improve dramatically as the spacecraft nears Neptune.

One-way light and radio transmission times between the Voyager 2 spacecraft and the NASA Deep Space Network receiver facilities at Madrid, Canberra and Goldstone, California, range from 3 hours, 57 minutes now to an expected 4 hours, 6 minutes at the closest approach. It takes over 8 hours for commands, sent from JPL's Space Flight Operations Facility, Pasadena, to reach the Voyager 2 spacecraft and be verified and sent back to Earth.

Because the JPL facilities associated with the Voyager project are not completely geared up for the close encounter activity, these views will be released in video format via satellite only. There will be no capability to release individual still photos for the complete video series. Current expectations, though, include the capability to release, on a periodic basis, a set of hard copy views which have received the benefit of further computer enhancement. JPL's complete computer processing capabilities will be up and running, though, for the encounter period from August 21 through 29. The Post-encounter phase runs from August 29 through October 2, at which time Voyager 2 will return to interplanetary cruise mode.

NASA will operate a full-time Voyager encounter news facility at JPL's von Karman Auditorium from August 21 through 29. Special programming from JPL will be broadcast over NASA Select during this period, and planetariums, schools, museums, and observatories who can receive NASA Select TV are encouraged to open their auditoriums to the public to view the Neptune encounter activities.

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JPL 410-15-87 6/89

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MISSION STATUS REPORT NO. 88 JULY 12, 1989

Add a New Neptunian Moon

A new moon has been discovered orbiting Neptune. Temporarily designated 1989 N1, the new moon was initially seen in images transmitted to Earth by Voyager 2 in mid-June. Its existence was confirmed upon examination of other images after the moon's orbital motion had been calculated and its position could be predicted.

The new Neptunian satellite could range in diameter from 200 to 600 kilometers (about 125 to 400 miles) and orbits in a very nearly circular and equatorial orbit about 92,700 kilometers (about 57,600 miles) from the planet's cloud tops (or about 117,500 kilometers (73,000 miles) from the planet's center).

A permanent name will be given to the moon at a later date by the International Astronomical Union (IAU).

According to Dr. Stephen P. Synnott, a Voyager imaging team scientist at JPL, the satellite appeared as a small, bright smudge in Voyager pictures due to the long (46-second) exposure. At this point, the moon is too indistinct to appear in photographic prints made from the Voyager images. Pictures taken in coming weeks will show the moon more clearly.

1989 N1 cannot be seen from Earth because the moon is so close to Neptune that the brightness of the planet itself masks the tiny point of light. Voyager 2 will continue to study the moon and will conduct searches for others on approach to the planet. Neptune has two other known moons: Triton, discovered in 1846, and Nereid, discovered in 1949. Triton is between 2,500 and 4,000 kilometers (1,500 to 2,500 miles) in diameter; Nereid probably is somewhere between 300 and 1,100 kilometers (200 to 700 miles) in diameter.

The moon orbits well outside the orbits of the postulated ring arcs. Its existence lessens concerns about radiation hazards to the spacecraft near the planet, since the moon probably sweeps charged particles out of the area as it orbits Neptune.

What do the Hieroglyphics Mean?

Images and some of the other data received at JPL from the two Voyager spacecraft are sent to display devices at JPL from the computers in JPL's Multimission Image Processing System. A subset of these data, primarily images, is being broadcast on the NASA Select TV channel by the GE Satcom F2R satellite. Currently, there is a one-hour broadcast every Tuesday through August 8. Broadcasts will probably be more frequent as Voyager 2 nears its closest approach to Neptune on August 25.

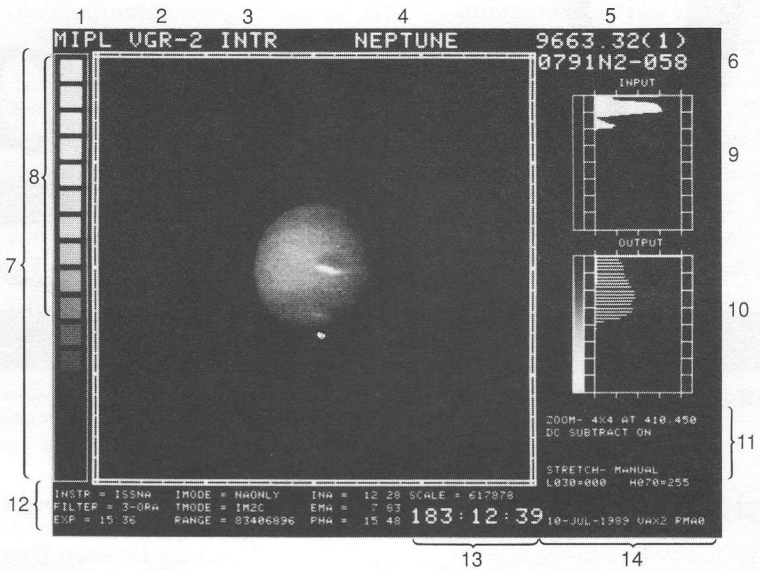
The frames that appear on the monitors are black and white only and include basic identification information for the image being displayed, as well as information about the processing that has been applied to that image. Data from the Planetary Radio Astronomy and Plasma Wave investigations can also be displayed on video devices. The following is a brief summary of the information shown for imaging, PRA, and PWS frames.

Imaging Frames

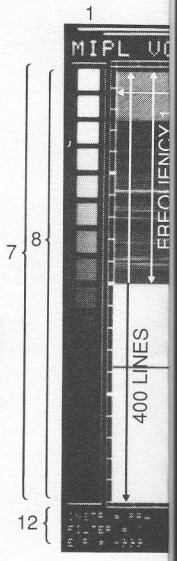
Each Voyager spacecraft carries two imaging cameras: a 200-mm, f/3.5 wide-angle camera using a refracting telescope and a 1500-mm f/8.5 narrow-angle (telephoto) camera using a reflecting telescope. Each camera uses a one-inch selenium-sulfur vidicon to convert

an optical scene into electrical signals. Each frame consists of 640,000 picture elements (pixels), each of which is expressed as a level of grey on a scale from 0 (black) to 255 (white). Color scenes are reconstructed on Earth by electronically combining images taken through different filters. The sensitivity of the filters ranges from 3460 (ultraviolet) to 6184 angstroms (red-orange). (The human eye can see in the range from 4000 to 7000 angstroms.)

The elements of the displayed imaging frames are described below.



Imaging frame



PRA frame

1. MIPL Multimission Image Processing System (a JPL facility)

2. Spacecraft Identifier (VGR-1 = Voyager 1; VGR-2 = Voyager 2)

3. System Source:

RLTM Real Time. The data is displayed from telemetry as soon as the data arrives at JPL; this data may be only 4 hours old (as long as it took for the data to travel from the spacecraft to Earth); it may have been taken earlier, recorded on the spacecraft's digital tape recorder, and played back to Earth at an optimum time; or it may have been stored at the Data Capture and Staging computer and read from there later. (See item 13, to learn when the data was received at Earth.)

INTR Interactive. Image is displayed from a work station where a scientist or analyst is interactively enhancing the data.

RPLA Replay, for NASA Select TV, of data received earlier.

4. Target Body (Neptune, Triton, Nereid, rings, etc.)

5. FDS Count. Image identification in units of spacecraft clock time (the spacecraft's clock is in the spacecraft's Flight Data Subsystem computers).

6. Frame identification in units of picture number (picno), planet, spacecraft, and days from encounter.

7. Frame. The data are displayed at half resolution. As displayed, the image area is 400 lines by 400 rows of picture elements. A full Voyager image frame is 800 lines of 800 picture elements, but since the display devices can display only 640x480 picture elements, every other pixel of every other line is displayed.

8. Reference Grey Scale.

9. Histogram (frequency distribution) of number of bits at each of the grey levels in the incoming image.

10. Histogram of number of bits at each of the grey levels in the image as displayed at left. (Note: the histograms are an aid in evaluating the quality of the displayed image; e.g., how bright was the image, how good was the exposure, etc.).

11. Describes processing that has been done to transform the input image to the output image; e.g., magnification factor, dark current subtraction, contrast enhancement.

12. Identification information:

INSTR Instrument:

ISSWA Imaging camera, Wide angle;

ISSNA Imaging camera, Narrow angle

FILTER Clear, green, orange, blue, violet, ultraviolet, methane (6910 or 5410 angstroms), or sodium.

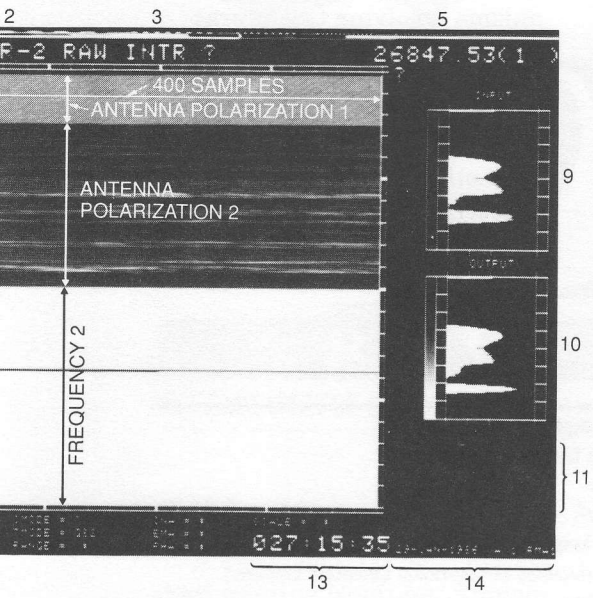
EXP Exposure time (seconds).

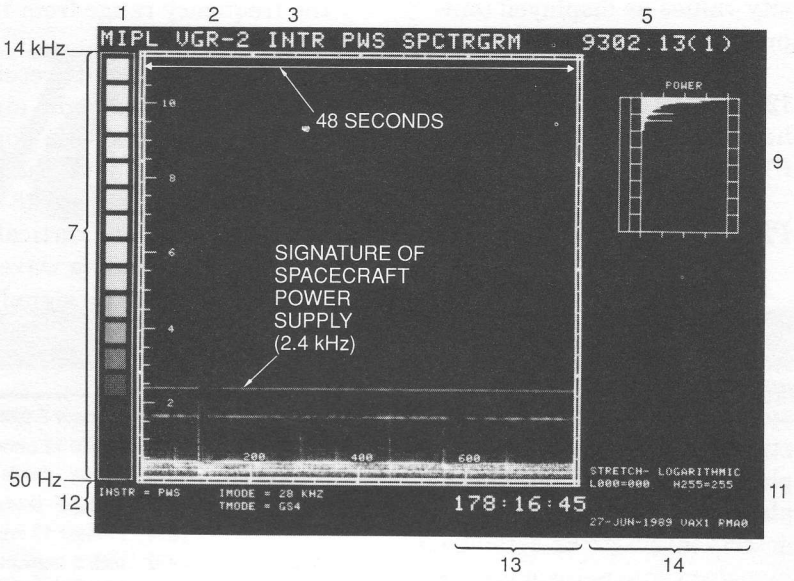
IMODE Shutter mode:

NAONLY Narrow angle only.

WAONLY Wide angle only.

BOTALT Wide and narrow angle shuttered alternately.





PWS frame

BOTSIM Both wide and narrow shuttered simultaneously.

BODARK Neither wide nor narrow shuttered (used to calibrate background noise [or "dark current"]).

NOSHUT Neither wide nor narrow read out.

TMODE Spacecraft telemetry mode at which data is read out (e.g., compressed, edited, slow scan, etc.).

RANGE Distance from spacecraft to center of target body, in kilometers.

INA Lighting angle (incidence angle of sunlight striking target).

EMA Viewing angle (emission angle of sunlight reflected from target).

PHA Phase angle (angle between incoming sunlight and emitted or reflected light from target).

SCALE Distance across frame (at the target body).

13. Time signal was received at Earth (day of year: hour: minute) in Universal Time Coordinated (UTC).

14. Calendar day (JPL local time), MIPS computer ID, display device ID.

Planetary Radio Astronomy (PRA)

The planetary radio astronomy experiment uses two 10-meter (33-foot) whip antennas to listen for radio emissions from the Sun, planets, and lightning in planetary atmospheres over a range from 1.2 kHz to 40.5 MHz. The PRA high-rate receiver gives high time resolution at two fixed frequencies that will be selected by the PRA science team when the spacecraft is a few weeks away from the planet. At Uranus the frequencies were 35.9424 MHz and 1.230 MHz.

Data from the PRA is sometimes displayed on the video devices. The following discussion indicates information that differs from the imaging frames.

7. Frame. A high-rate PRA frame contains 48 seconds of data formatted as 800 lines, each containing 800 8-bit samples. The total time per line is 0.06 second. Only one-fourth of the PRA data is displayed in the video conversion of the frame. The first 24 seconds of the displayed frame represent signals at the first fixed frequency, at two antenna polarizations. The last 24 seconds show only one polarization at the second fixed frequency. "Real" signals show as horizontal white (or light) streaks running across the frame. (The example above shows lightning-like electrical discharges at Uranus.)

The pattern observed in each line represents the "loudness" as a function of time, of an "audio" noise signal in a narrow band centered on the receiver frequency. Real data increases the "loudness" of the signal, just like extra static in a home radio. The amount and type of noise gives information about what causes it.

9. Histogram of signal intensity as received (input).

10. Histogram of signal intensity values as displayed (output).

12. Only **Instru** and **TMODE** have any meaning for PRA and PWS frames.

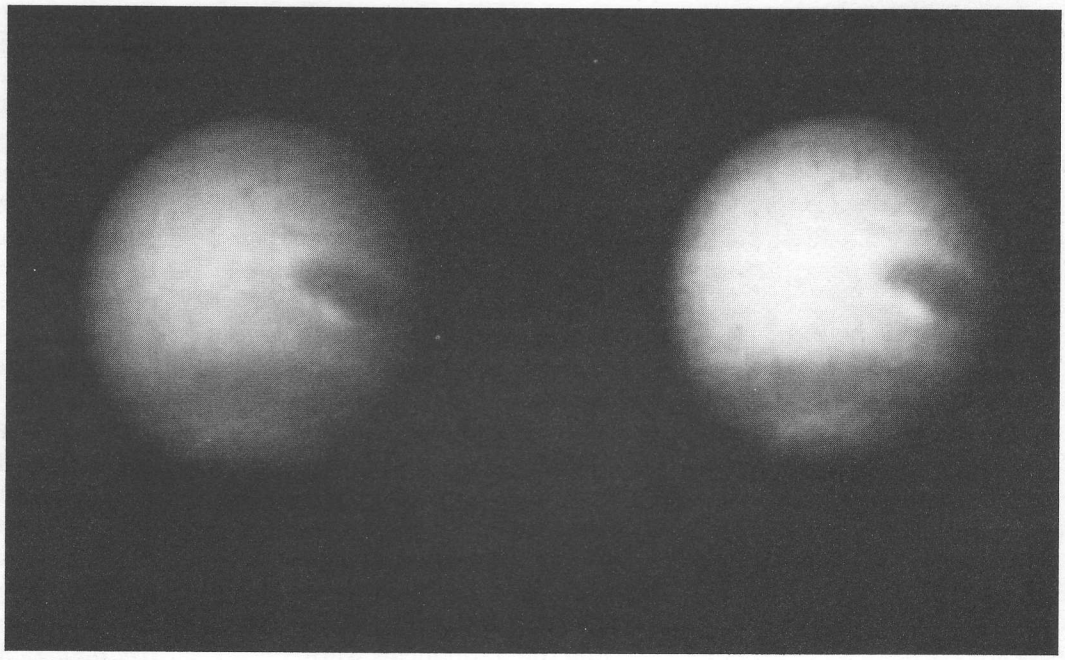
Plasma Waves (PWS)

Plasma waves are low-frequency oscillations in the plasmas in interplanetary space and in planetary magnetospheres. The plasma wave instrument detects and measures plasma wave interactions in planetary magnetospheres and detects interactions between a planetary magnetosphere and the solar wind. It can detect particles in the ring plane and measure their impact rate on the spacecraft. The PWS shares the two whip antennas with the PRA investigation to provide the equivalent of a single 7-meter antenna. PWS covers the frequency range from 10 Hz to 56.2 kHz.

The PWS high-rate receiver is a very sensitive audio amplifier. In the display of a Fourier transform of the data, the horizontal axis is time (one 48-second frame) and the vertical axis is frequency. Plasma wave scientists interpret the signal patterns in terms of various mechanisms involving the interactions of charged particles and electromagnetic waves. Steady frequencies generally are associated with interference signals from other subsystems on the spacecraft; for example, the 2.4 kHz hum of the spacecraft's power supply is pointed out on the sample frame.

Some Space Science Summer Anniversaries

July 9	**1979**	**Voyager 2 encounters Jupiter**
July 20	**1969**	**Apollo 11 crew become first men on the Moon**
	1976	**Viking 1 lands on Mars**
August 8	**1976**	**Viking 2 lands on Mars**
	1978	**Pioneer 13 multiprobe launches to Venus**
August 12	**1978**	**ISEE 3 launches (later renamed International Cometary Explorer)**
August 20	**1975**	**Viking 1 launches to Mars**
	1977	**Voyager 2 launches to Jupiter and Saturn**
August 25	**1981**	**Voyager 2 encounters Saturn**
September 5	**1977**	**Voyager 1 launches to Jupiter and Saturn**
September 9	**1975**	**Viking 2 launches to Mars**
	1978	**Venera 11 launches to Venus**
September 11	**1985**	**International Cometary Explorer rendezvous with Comet Giacobini-Zinner**
September 14	**1978**	**Venera 14 launches to Venus**



Neptune's dark oval cloud system, which is bigger than the entire planet Mars, and a dusky collar—actually a double ring—around the south pole are the first major discoveries by Voyager 2 at Neptune. The image on the right is an enhanced version of the image on the left. (P-34375)

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JPL 410-15-88 7/89

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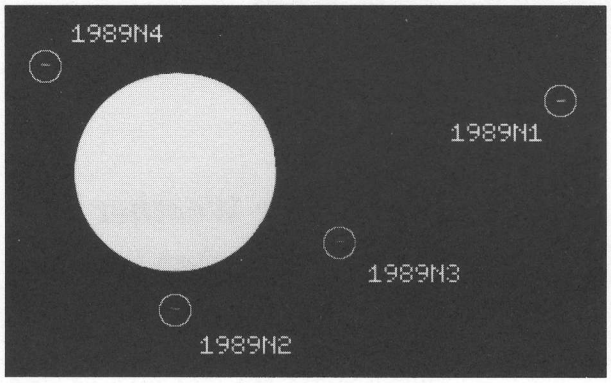
Voyager

BULLETIN

MISSION STATUS REPORT NO. 89 **AUGUST 7, 1989**



Neptune's four new small moons appear as streaks due to motion of the spacecraft during this 46-second exposure. Neptune is severely overexposed so the new moons can be distinguished. (P-34540)

Moons, Moons, Moons

As some scientists have expected, Neptune is proving to have a large family of moons too small to be seen from Earth-based telescopes. Three additional new moons have recently been confirmed in images returned from Voyager 2 from a distance of about 22 million miles from Neptune.

The discoveries bring the current total number of Neptune moons to six, with more moons expected to be discovered as Voyager 2 nears the planet. Scientists would have been more surprised had no new moons been found near Neptune. Small moons are believed to play a part in maintaining the orbits of ring particles at Jupiter, Saturn, and Uranus. Neptune is believed to have partial arcs or rings.

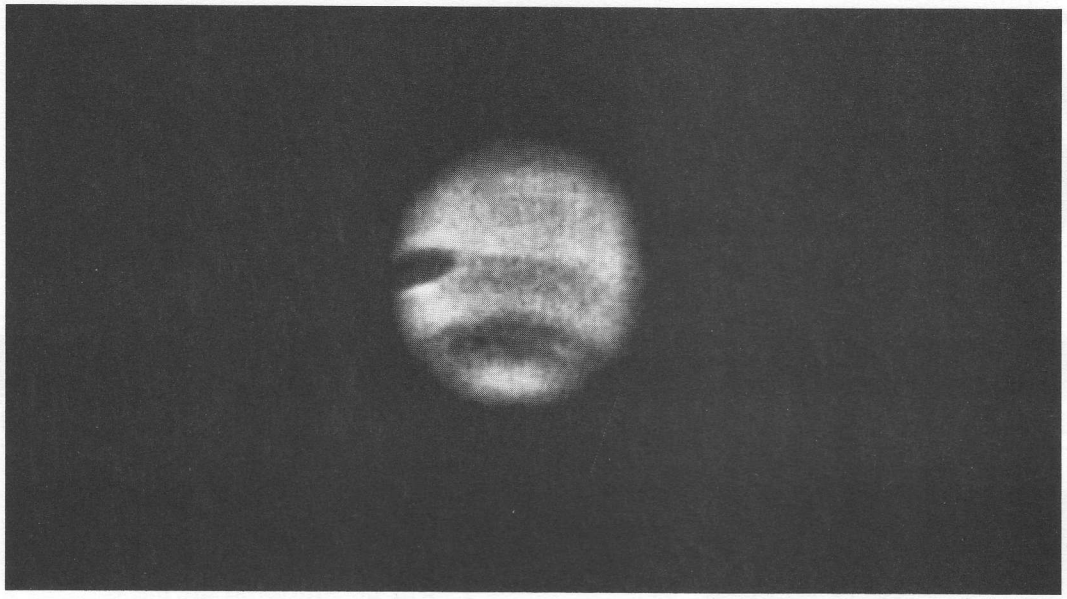
The three newest moons, temporarily designated 1989 N2, 1989 N3, and 1989 N4 in order of their discovery, orbit in the region where the ring arcs are believed to exist, based on Earth-based telescopic observations. All of the new moons are smaller than the 200- to 600-km diameter moon 1989 N1 discovered in July, and occupy nearly circular and equatorial orbits around the planet.

The computer sequence that contains the instructions for Voyager 2's near-encounter observations has recently been altered to add one image of 1989 N1 from a distance of 140,000 km (87,000 mi), about 45 minutes before the spacecraft's closest approach to Neptune on August 25. The image will be shuttered during a radio science antenna calibration maneuver, which fortuitously turns the spacecraft at just the right rate to remove most of the image smear which would otherwise result because of the high relative velocities between the spacecraft and the target. The resulting image should show surface features as small as 3 km (2 mi) on this small moon.

The fact that all of the new moons orbit in the same direction as the planet rotates makes the large moon Triton even more of an oddity, since it orbits in the opposite direction. Current theories of solar system formation suggest that the planets and moons formed out of a swirling disk of gases and dust and, thus, all should rotate and orbit in the same direction.

Moon or Ring Arc	Orbital Radius (from Center of Neptune)*		Orbital Period
Postulated Inner Arc	42,000 km	(26,100 mi)	~6 hrs
1989 N3	52,000 km	(32,300 mi)	8 hrs 10 min
Postulated Interior Arc	57,000 km	(35,420 mi)	~9 hrs
1989 N4	62,000 km	(38,500 mi)	10 hrs 20 min
Postulated Outer Arc	67,000 km	(41,600 mi)	~12 hrs
1989 N2	73,000 km	(45,400 mi)	13 hrs 30 min
1989 N1	117,650 km	(73,100 mi)	26 hrs 56 min
Triton	354,590 km	(220,340 mi)	5 days 21 hrs
Nereid	5,510,660 km	(3,424,300 mi)	359 days

*Subtract one Neptune radius (24,712 km at 1 bar pressure level) to calculate distance from Neptune's cloudtops.



Embedded in the middle of Neptune's dusky southern collar is a dark oval with a bright central core. (P-34504)

Course Correction

Voyager 2's path towards Neptune was fine-tuned slightly on August 1, when a course correction moved the spacecraft slightly sideways and changed its velocity by about 2.1 miles per hour. After re-orienting itself as instructed by flight controllers, the spacecraft expelled pressurized hydrazine (N_2H_4) fuel for about seven and a half minutes to change its course.

At launch, each Voyager spacecraft carried about 105 kilograms (230 pounds) of hydrazine propellant in a pressurized tank. To date, Voyager 2 has expended about 64 kilograms (140 pounds) of hydrazine. Each spacecraft has four thrusters for trajectory correction maneuvers and twelve thrusters for attitude control (attitude refers to the spacecraft's orientation in space, using the Sun and a star as references), and each thruster delivers about 0.2 pounds of thrust.

Current plans include two more trajectory correction maneuvers, on August 15 and 21, to fine-tune the flight path for Neptune. Accurate delivery of the spacecraft to the Neptune aimpoint is especially important to the radio science experimenters, who must know the timing of the start of the spacecraft's disappearance behind Neptune as seen from Earth (Earth occultation) with an accuracy of 1 second.

Neptune's Weather

Neptune's cloudtops show a surprising amount of variability, considering that Neptune receives about two-tenths of a percent as much power per unit area as does the Earth, and about 4 percent as much as Jupiter. These estimates take into account both energy received as sunlight and energy upwelling from the planet's interior. This energy is a factor in creating weather systems on all planets.

While the large dark oval, first seen this spring, has remained relatively constant in position, a bright cloud to the north and east was seen to separate from the dark spot over a 53-hour interval from July 9 to 12. In addition, a smaller dark spot apparent in the dark collar near the south pole rotates faster than the large dark spot. This finding indicates that the winds on Neptune have different velocities at different latitudes, as is the case for Jupiter, Saturn, and Uranus.

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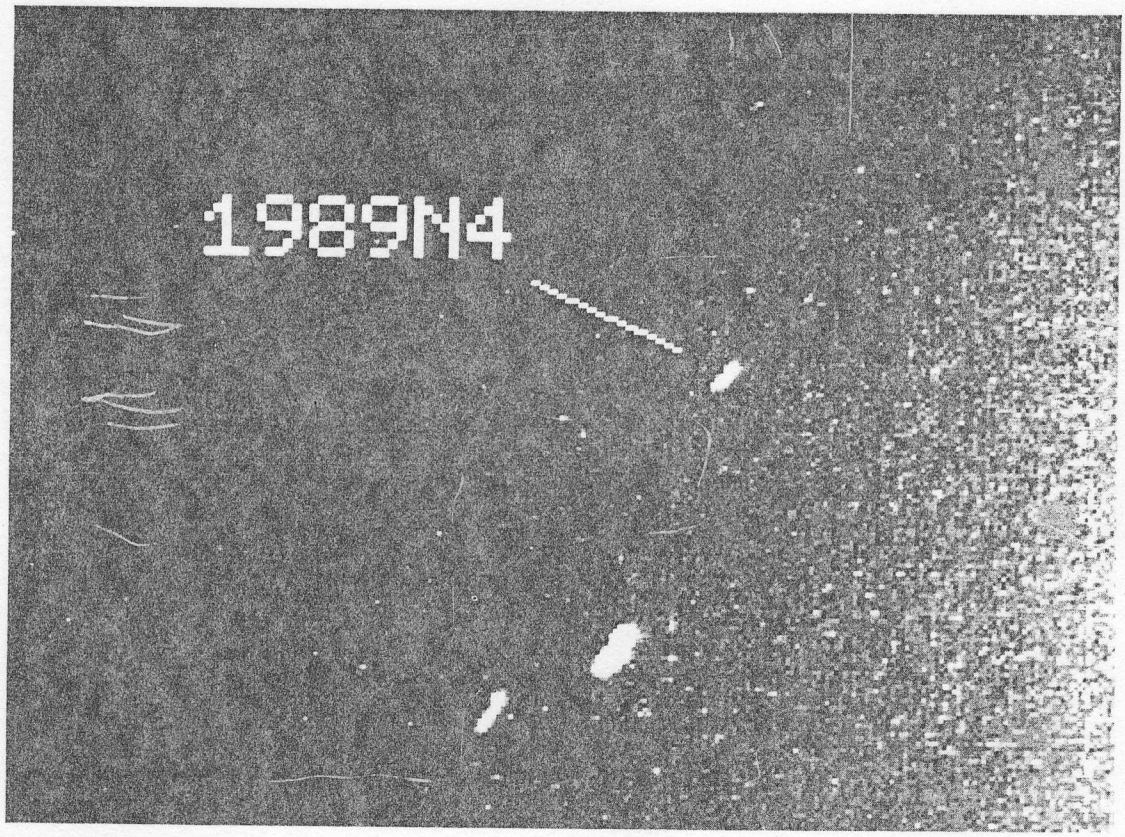
B U L L E T I N

MISSION STATUS REPORT NO. 90 AUGUST 11, 1989



One of two ring arcs discovered in Voyager 2 images is seen just outside the orbit of the recently discovered moon 1989 N4. (P-34578)

Ring Arcs Confirmed!

Voyager's imaging science team has found two of the long-sought-after ring arcs, or partial rings, thought to exist around Neptune. The arcs were found in photographs returned by Voyager 2 early in the morning on August 11.

The two ring arcs are apparently associated with two of the Neptunian moons also found by Voyager 2 earlier this month. The arcs appear to wrap approximately 45 degrees and 10 degrees, respectively, in the planet's equatorial plane. One is about 50,000 kilometers (about 30,000 miles) in length; the second is about 10,000 km (about 6,000 mi) long.

The first arc, the longer of the two, was seen just outside the moon 1989 N4, which orbits about 62,000 km (38,500 mi) from the planet's center, or about 37,000 km (23,300 mi) from the planet's cloud tops.

The second arc appears to trail the moon 1989 N3 by approximately 90 degrees, or by about 80,000 km (50,000 mi). That moon orbits Neptune at a distance of about 52,000 km (32,300 mi) from the center of the planet, or about 27,300 km

Continued on page 4

Far-Encounter Phase

On August 6, Voyager 2 began its eighteen-day "far-encounter" phase, which ushers in a higher level of activity than the just-completed "observatory" phase. Neptune's disk now captures about one-quarter of the narrow-angle camera's field of view.

Higher activity also means more telemetry data, so NASA's Deep Space Network (DSN) has added daily tracking coverage by the Very Large Array (VLA) in New Mexico and the Parkes Radio Telescope in Australia, in addition to 24-hour coverage by the DSN complexes.

The far-encounter phase started with an intensive series of scans across the Neptunian system enabling the ultraviolet spectrometer to search for auroral emissions from the planet. These system scans occur four or more times per day. The imaging cameras are focusing on the large-scale features in Neptune's atmosphere, the newly discovered ring arcs, searches for new satellites, and on the other known satellites, as well. Bursts of high-rate data from the planetary radio astronomy (PRA) instrument and the plasma wave subsystem (PWS) are being recorded twice per day for later playback to Earth.

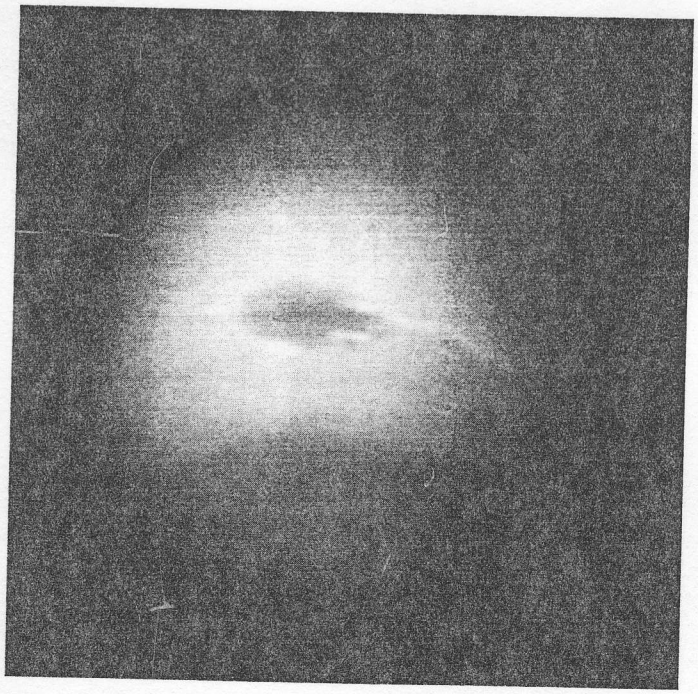
Also on August 6, the last full-scale dress rehearsal for the encounter, the final radio science operational readiness test, was conducted. The ten-hour test involved Voyager 2 and the tracking stations of the world-wide DSN.

On August 11, the health of the infrared instrument (IRIS) was assessed in preparation for the high-value observations later in far encounter. Over the years, IRIS has experienced a degradation in its sensitivity due to misalignment of its mirrors. Periods of heating (using tiny heaters on board the spacecraft) reduce crystallization of mirror bonding material and restore some of the original sensitivity, but stabilization of the instrument response requires several weeks of cooling prior to data-taking. A strategy to maintain careful balance between heating and cooling periods has been applied.

As Voyager 2 homes in on Neptune, activities on board the spacecraft require more of its computers' memory, so on August 13 the current backup mission load (BML) will be permanently removed from spacecraft to free up much-needed memory space. Removing the BML is a calculated risk, as the sequence is designed to autonomously operate the spacecraft through a minimum set of encounter observations should the spacecraft's only remaining radio receiver fail and prevent ground controllers from sending further commands to the spacecraft. Another BML will be loaded in the post-encounter phase to protect future long-term fields and particles observations in the outer solar system.

Neptune's position is now known about three times more accurately than just two weeks earlier; Triton three to six times better, depending on the component. Knowledge of the time of arrival is one-third better. Soon, the value of Triton's radius will no longer be a mystery. And by this time, the mass of Neptune is known three times better than at the start of the far-encounter phase, because the subtle tug of the planet's gravity can already be detected in Voyager's radio data.

On August 15, Voyager 2 will again fine-tune its flight path, following instructions arrived at after laborious computations by Voyager's Naviga-



Features at different latitudes move at different rates; their relative motions are a measure of atmospheric wind speeds. (P-34558)

tion and Spacecraft Teams. Immediately following this trajectory correction, Voyager 2 will turn about its roll axis to acquire a different lock star for its star tracker (the spacecraft uses the Sun, the Earth, and a star to maintain its orientation). This change from Achernar to Canopus will place the onboard fields and particles instruments in a better orientation for measuring magnetospheric properties during the days before Neptune closest approach.

The highest-value science observations in this phase will be the IRIS instrument's observations of the planet on August 16-18; the matching outbound observation in the post-encounter phase is equally important. These observations will tell us the planet's temperature, which may be combined with other Voyager data to provide the heat balance—the ratio of the amount of energy being given off by the planet to the amount of energy it receives from the Sun. This is a highly important measurement to make for planets (especially the gaseous ones) since it allows scientists to deduce things about the body's interior, and unlock some of the secrets hidden by its clouds. The optimum times to make the heat balance measurements will be on August 18 (inbound) and September 1 (outbound) when Neptune's disk should just barely fill the IRIS instrument's field of view.

The week before the spacecraft's closest approach to the planet (on August 25) will be filled with specialized observations of Neptune and its atmospheric features, its ring-arc system, Triton, Nereid, and the recently discovered small satellites. All eleven of Voyager's science investigations will be actively taking data. Fields and particles instruments will continue their search for Neptune's magnetosphere. The unambiguous sign of Voyager's entry into this strange domain of "whistlers," "chirpers," and electromagnetic static and hissing will be the crossing of the "bowshock" and the magnetopause region, estimated to occur between about 27 and 9 hours before Voyager 2's closest approach to Neptune.

Most of the flight teams will be busy night and day, analyzing data and dealing with any unexpected problems. The Navigation Team will be working especially hard to calculate all of the values needed for the final course correction and the late updates to the pointing and timing of critical observations.

The final aiming point for the encounter will be fixed on August 20 with the final course correction of Voyager 2's 12-year odyssey to the outer planets. After this, no changes to the flight path are planned—ever—for Voyager 2. Its fate will thus be transferred to the final slingshot over Neptune's northern polar region and the meager forces it may encounter in interplanetary and interstellar space.

This final maneuver is designed to adjust Voyager 2's position to heighten the probability that Voyager 2 will pass through the narrow area of space where Triton casts its shadow from the Sun and the Earth. Critical observations of Triton's atmosphere depend on passing through this region.

Mission Summary

Planet	Average Distance from Sun	Spacecraft	Elapsed Travel Time	Encounter Date	.One-way Communications Time**	Max. Data Rate (bits/s)	Closest Approach Dist. (km) (from center of planet)	Closest Approach Dist. (km) (from cloud tops)
Earth	1 AU*	Voyager 1	Launched Sept 5, 1977					
		Voyager 2	Launched Aug 20, 1977					
Jupiter	5.202561 AU	Voyager 1	18 mos.	Mar 5, 1979	37 min	115,200	348,890	277,400
		Voyager 2	23 mos.	Jul 9, 1979	52 min	115,200	721,670	650,180
Saturn	9.554747 AU	Voyager 1	3 yrs 2 mos	Nov 11, 1980	1 h 24 min	44,800	184,240	123,910
		Voyager 2	4 yrs	Aug 25, 1981	1 h 26 min	44,800	161,094	100,830
Uranus	19.21814 AU	Voyager 2	8 yrs 5 mos	Jan 24, 1986	2 h 45 min	21,600	107,000	81,440
Neptune	30.10957 AU	Voyager 2	12 yrs	Aug 25, 1989	4 h 6 min	21,600	29,183	4,850

* 1 astronomical unit (AU) equals 149,597,870 km (92,960,116 mi)
** Radio waves travel at the speed of light (299,792.458 km/s or 186, 291.033 mi/s)

RING ARCS Continued from page 1

(about 17,000 mi) from the planet's cloud tops.

Astronomers have long suspected the existence of such an irregular ring system around Neptune. Data from repeated ground-based observations hinted at the existence of disorderly strands of partial rings orbiting Neptune. Voyager's photographs of the ring arcs are the first photographic evidence that such a ring system exists.

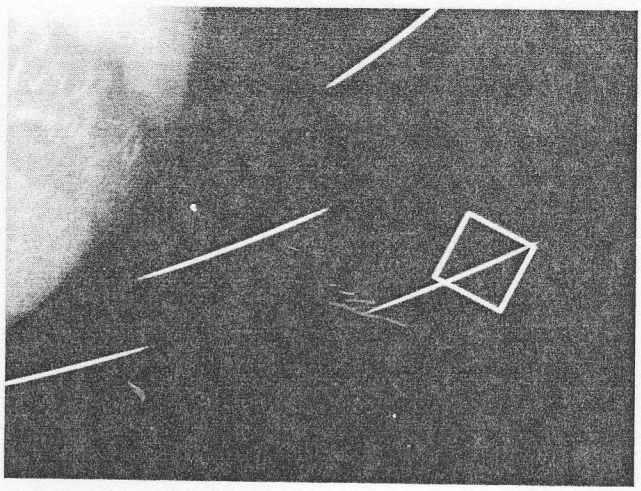
Voyager scientists said the ring arcs may be comprised of debris associated with the nearby moons, or may be the remnants of moons that have been torn apart or ground down through collisions. Close-up studies of the ring arcs by Voyager 2 in coming days should help determine their composition.

More ring arcs are expected to be found as the spacecraft nears the planet, Voyager scientists said.

Discovery of the two arcs when the spacecraft was still about 21 million km (13 million mi) from Neptune gives the Voyager team time to schedule detailed imaging of the ring arcs when the spacecraft comes within 4,850 km (3,000 mi) of the planet the night of August 24/25.

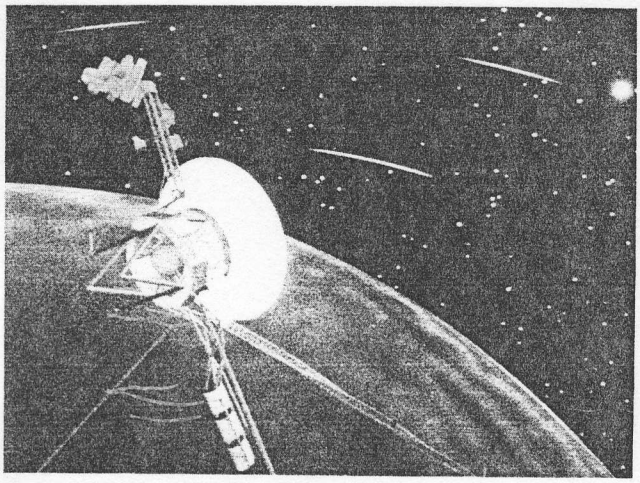
Recorded Status

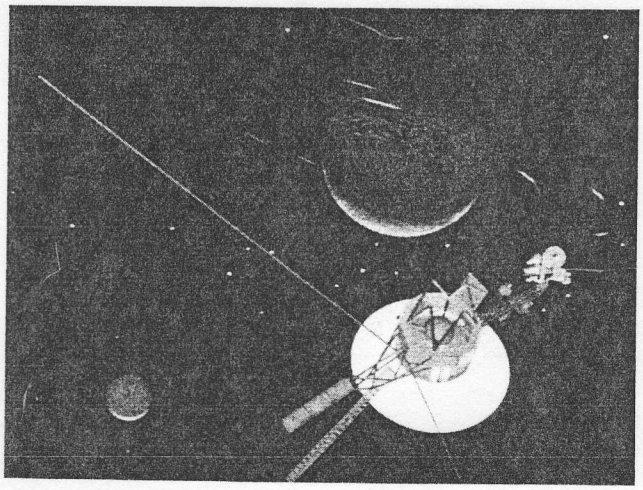
Recorded mission status reports are now available by calling 818-354-0409.



Detailed observations of the newly-discovered ring arcs will include imaging, photo-polarimetry, and radio experiments. (P-34513)

As Voyager 2 slips behind the planet, the radio science experiment will execute a precisely timed limb-tracking maneuver to study the planet's atmosphere. (P-34514BC)





Its last planetary mission fulfilled, Voyager 2 will catch a final glimpse of the crescents of Neptune and Triton. (P-34516BC)

Credits: Voyager Mission Planning Office and JPL Computer Graphics Lab

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JPL 410-15-90 8/89

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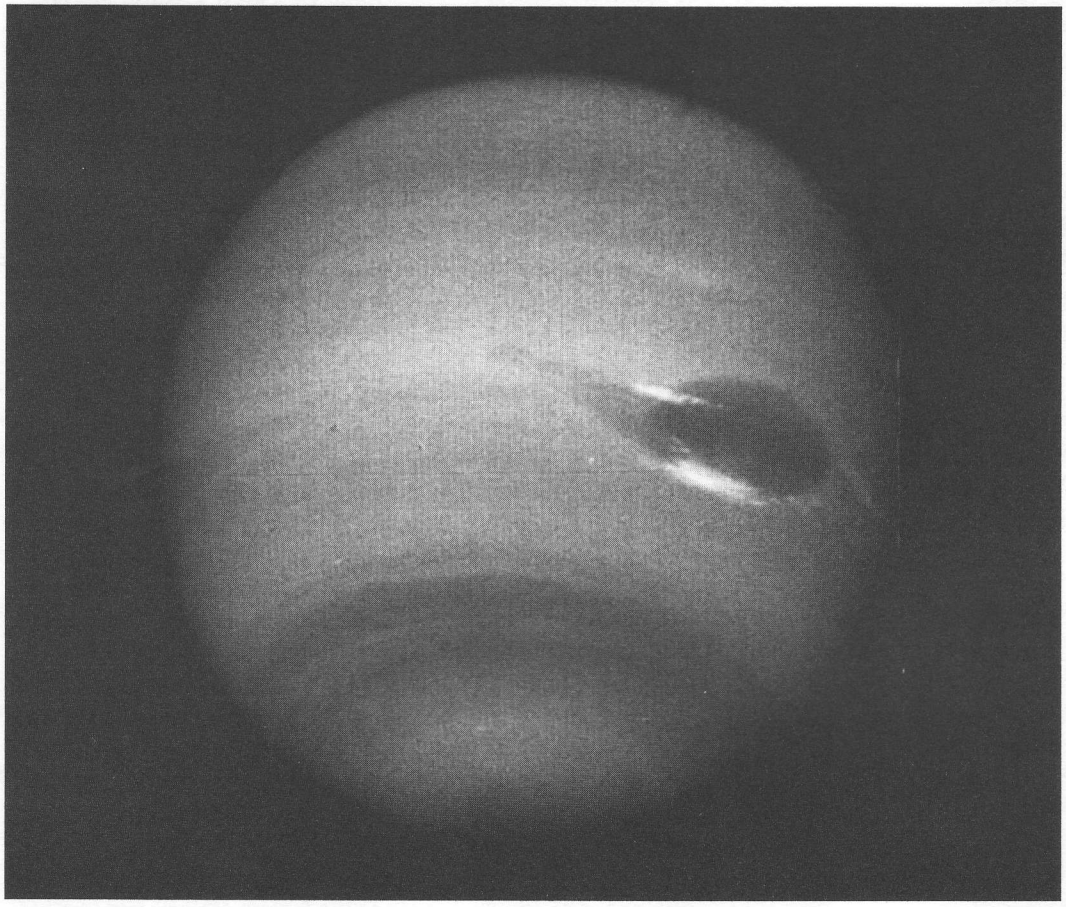
BULLETIN

MISSION STATUS REPORT NO. 91 AUGUST 17, 1989



A dark feature extending westward and northward toward the equator from the Great Dark Spot (GDS) developed over a relatively short period (three rotations or about 54 hours), and continues to evolve with time. (P-34594 BW)

Intriguing . . .

As Voyager 2 approaches Neptune, rapidly increasing image resolution is revealing striking new details in the planet's atmosphere, including features as small as a few hundred kilometers in extent. Bright, wispy "cirrus-type" clouds overlie the Great Dark Spot (GDS) at its southern margin and over its northwest boundary. This is the first evidence that the GDS lies lower in the atmosphere than these bright clouds, which have remained in its vicinity for several months. Increasing detail in global banding and in the south polar region can also be seen; a smaller dark spot at high southern latitudes is dimly visible.

Further study may reveal whether a dark feature seen extending north and west toward the equator from the Great Dark Spot represents an actual flow of dark cloud material from the GDS or is a result of atmospheric disturbances associated with the western boundary of the GDS.

Look for Voyager 2 near Sagittarius

Obviously, we can't see anything as small as the Voyager spacecraft four and a half billion kilometers away, but we *can* locate Neptune in the night sky, and thus imagine Voyager 2's position. Looking low on the western horizon just after sunset, one can see Saturn, just above the constellation Sagittarius. To the left and above Saturn will be Neptune. For readers familiar with astronomy, Neptune's coordinates on August 24 will be right ascension 18 hours 42 minutes, declination -22 degrees 11 minutes, and its magnitude will be 7.9.

Highlights of the Near-Encounter Phase

Most of the high-value science Voyager 2 will gather during the entire four-month encounter period will come during a 53-hour period spanning August 24, 25, and 26.

By then, Neptune will completely fill the wide-angle (WA) camera's field of view (55.6 x 55.6 milliradians), which looks at fifty times more viewing area than the narrow-angle (NA) camera (7.5 x 7.5 mrads). Triton, for so long just a few pixels across even in the narrow-angle camera, will fill half the narrow-angle camera's field of view.

Near the start of the near-encounter sequence, on August 24, the 70-m antenna in Canberra, Australia, will transmit to the spacecraft a precise tone at the X-band frequency (about 8400 megahertz). The tracking stations near Madrid, Spain, will then carefully listen to Voyager's return signal more than eight hours later (the signals, traveling at the speed of light, will take more than four hours each way to travel the 4.5 billion kilometers between the spacecraft and Earth). With Neptune tugging on Voyager, there will be a measurable Doppler shift, which can then be used to deduce the strength of Neptune's gravity.

Every six minutes, the low-energy charged particle detectors will collect high-rate samples of the flow directions of charged particles in Neptune's (expected) magnetosphere.

About eleven hours before Neptune closest approach (N-11h), Voyager 2 will take its best picture of the small moon Nereid, which will span less than 20 pixels in the narrow-angle frame (Neptune was this size in January 1989).

From N-10h to N-8h, the infrared instrument will be trained on a spot in Neptune's atmosphere at -40.4 degrees south latitude. This is the latitude Voyager's radio signal will pass through as the spacecraft reappears from behind the planet at the end of its Neptune Earth-occultation experiment, 55 minutes after Neptune closest approach. Using the data collected from this infrared observation, scientists can later determine the helium abundance at this occultation egress point, as it is called. These data will provide pieces of the puzzle needed to determine the overall atmospheric structure and composition.

After imaging, infrared, and photopolarimetric observations of Neptune's sunlit limb (edge), Voyager will next train its cameras on the ring-arc region. Between N-7h 17m and N-6h 22m, two retargetable ring-arc observations will employ for the first time a clever technique called Nodding Image Motion Compensation (NIMC) to "freeze" the motion of selected clumps of orbiting ring-arc material. (NIMC "nods" the spacecraft just enough to track the target but not enough to break the antenna's line of sight to Earth, thus allowing the data to be returned to Earth as it is taken, rather than recorded onboard the spacecraft for later playback to Earth.) Between the two ring observations, Voyager has been reprogrammed to shutter four images of the recently discovered moon 1989N2.

By N-5h 18m, a photopolarimetric and ultraviolet scan of Neptune's bright limb will be completed. Ring observations will continue for almost two more hours. Between N-4h 55m and N-3h 3m, the sensitive detectors in the photopolarimeter and ultraviolet spectrometer will gaze at the star Sigma Sagittarii (also known as Nunki) as it appears to drift behind the right-hand half of the ring-arc system as a result of Voyager's motion. This stellar occultation may provide detailed ring-arc region structural and orbital data.

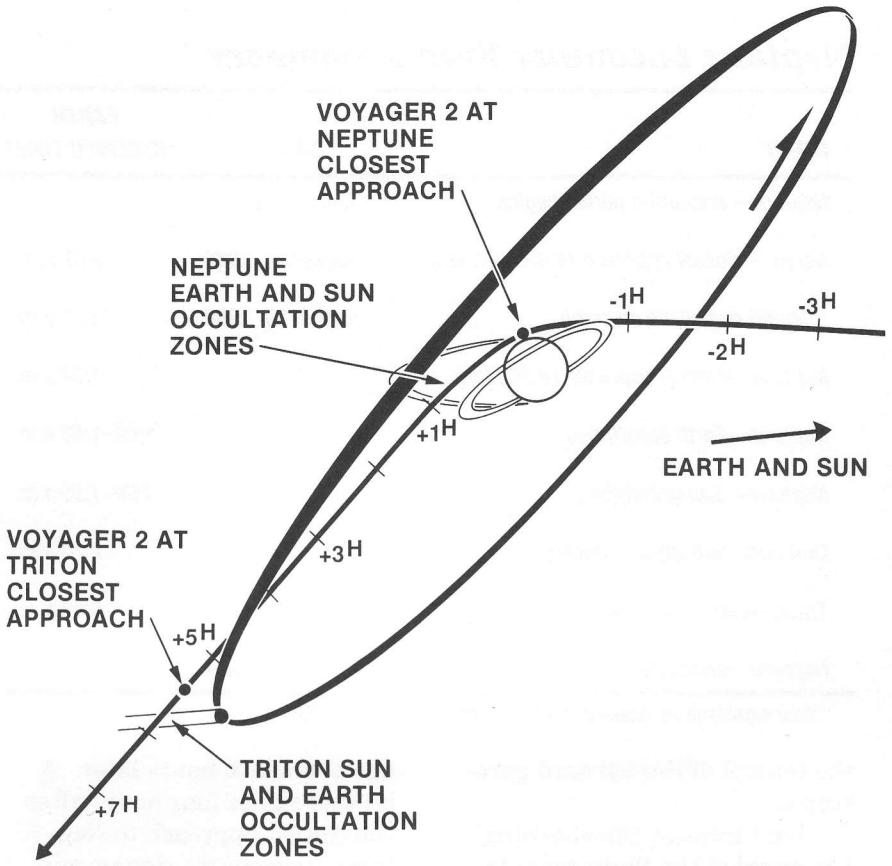
While the bright limb scans and stellar occultations are taking place, Voyager 2 will be receiving updated instructions from Earth. All of the science observations between about N-3.5h and N+9h are sequenced in three separate movable blocks that can be shifted in time. The Neptune Movable Block (NMB) contains the spacecraft's instructions for all activities around Neptune closest approach from N-3h 20m to N+1h 46m; the Triton

Movable Block (TMB) contains the observations around Triton closest approach from N+1h 50m to N+8h 38m; and the Vernier Movable Block (VMB) encompasses the critical sequence for controlling the Neptune radio science occultation from N-5m to N+56m. The Vernier Movable Block overlies the Neptune Movable Block.

By allowing the entire block of activities in each block to shift, timing updates can be applied to the whole set in one simple step, instead of changing individual timing parameters in each observation. Shifts in multiples of 48 seconds are possible for the NMB and TMB; for the VMB, a special technique will allow shifts in radio science occultation events of as little as one second, independent of how much the NMB is shifted. The success of the radio science measurements is dependent upon the Navigation Team's ability to estimate the time of closest approach to within one second. For everything except the critical radio science occultation, 48 seconds would be good enough.

Other updates in these instructions will also control scan-platform pointing to several high-value targets, spacecraft rates for the radio science occultation maneuver, and rates for a critical Triton Image Motion Compensation (IMC) maneuver.

By N-3h, another retargetable ring-arc observation will be finished. The best image of Triton before Neptune closest approach will be taken: Triton will subsequently be eclipsed by Neptune's southern limb, and won't be visible again until the spacecraft arcs over Neptune's



Voyager 2's closest approach to Neptune on August 25 (GMT) will be about 3000 miles above the planet's cloudtops. Five hours later, the spacecraft will fly within about 23,900 miles of the moon Triton.

pole. The scan platform will shift back to Neptune for some imaging, infrared, and photometry measurements. The Low-Energy Charged Particle (LECP) instrument will switch into a higher-energy sampling mode as Voyager 2 penetrates the deepest part of Neptune's magnetic field and radiation belts. The other fields and particles instruments will also add to the flood of data.

At N-1h 41m, the sensitive optics of the instruments on the scan platform will be pointed away from Neptune—towards deep space—to protect them from possible pitting during the inbound ring-plane crossing. Then, one hour from its aiming point, Voyager 2 will configure its radio transmitter for the ring-arc system and Neptune occultations, calibrate its antenna, and gather baseline pre-occultation data until N-20m.

For about ten minutes centered around N-56m, the spacecraft will cross the ring plane just outside the ring-arc region. The plasma wave instrument should pick up the sounds of microscopic (harmless) ring particles vaporizing as they hit the spacecraft.

Immediately after the ring-plane crossing, the spacecraft will roll 61 degrees from the lock star Canopus to orient the fields and particles instruments for measurements of the charged particles that should be raining into Neptune's north pole along the magnetic field lines, perhaps causing auroral activity ("northern lights"). At the end of this roll, the spacecraft's attitude will be under

Neptune Encounter Events Summary

EVENT	DATE	EARTH RECEIVED TIME*
Neptune—encounter period begins	*June 5, 1989*	
Nereid—closest approach (4,655,000 km)	*August 24, 1989*	*9:02 p.m.*
Inbound ring-plane crossing	*August 25, 1989*	*12:01 a.m.*
Neptune—closest approach (4,900 km)		*1:03 a.m.*
Neptune—Earth occultation		*1:09–1:58 a.m.*
Neptune—Sun occultation		*1:09–1:59 a.m.*
Outbound ring-plane crossing		*2:24 a.m.*
Triton—closest approach (38,360 km)		*6:17 a.m.*
Neptune—encounter period ends	*October 2, 1989*	

**Time signal will be received at JPL, Pacific Daylight Time (PDT).*

the control of the onboard gyroscopes.

Last-minute "shoehorning" has enabled the flight team to insert an instruction to Voyager 2 to shutter a high-resolution image of the recently discovered moon 1989N1 about 45 minutes before the closest approach to Neptune. By a stroke of luck, the image can be taken during a radio science antenna pointing calibration maneuver, which provides almost perfect image motion compensation. Details as small as 2.5 kilometers across should be visible on this small moon's disk.

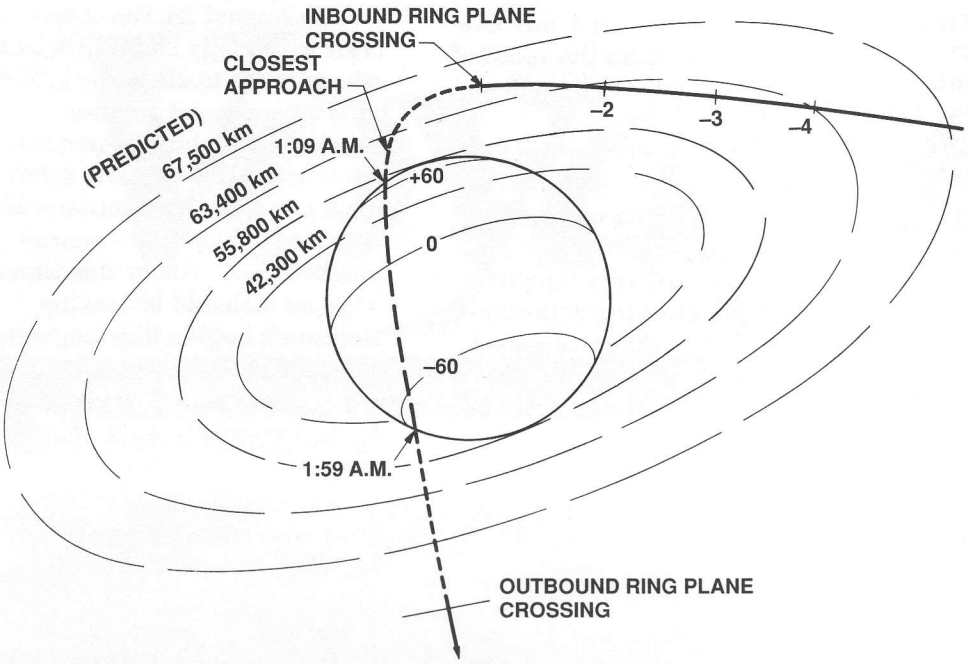
With pure X- and S-band tones emanating from Voyager 2, the radio science ring occultation will begin at about N-60m and extend until about N+5m. Back on Earth, the spacecraft will rise above the horizon over the Deep Space Network sites in Australia. The Australian government's Parkes Radio Telescope will join the DSN's tracking coverage about two hours later. A bit more than four hours after the closest approach to Neptune, Voyager 2's signals will arrive at the arrayed antennas, distorted in meaningful ways by their passage through Neptune's ionosphere, ring-arc system, and atmosphere.

At N-5m, the duration of each of Voyager's thruster pulses will be increased from four-thousandths of a second to ten-thousandths, just in case Neptune's atmosphere applies some unexpected drag on the vehicle, and also to provide quicker response to maneuver commands needed for the occultation experiment. This special provision will remain in place for the next hour. The shift of the Vernier Movable Block will precisely control the timing for all occultation activities for the next hour. Since the telemetry stream will have been turned off an hour earlier to concentrate power in the pure radio signal, all spacecraft telemetry during this time will be routed to the tape recorder for later playback.

Voyager 2's speed relative to Neptune is expected to peak at an impressive 98,350 km/h (60,980 mi/h) as it silently and effortlessly sails through its aiming point—right on target—a mere 4400 km (2730 mi) above Neptune's sensible atmosphere, and only 4900 km (3000 mi) above the methane cloudtops below. This is by far the closest Voyager 2 will come to any body since it left Earth twelve years ago. As it arcs over 77 degrees north latitude, the spacecraft will start to slow down, and begin its permanent journey down and out of the ecliptic plane.

As Voyager 2 approaches the dark side of the planet, Neptune's sunrise terminator will pass beneath, and within about six minutes after closest approach, Voyager will watch with a special ultraviolet Sun-viewing port as the distant Sun disappears into Neptune's ever-thickening atmosphere.

With its pure-tone transmissions still turned on—and while completely out of view from the Earth—the automated spacecraft will perform an amazing string of 24 maneuvers, collectively known as the "limbtrack" maneuver, to precisely point the boresight of the spacecraft's high-gain antenna along Neptune's limb, starting with the ingress point in Neptune's northern hemisphere, then around the left limb (as viewed from Earth), and ending with the egress point at -40.4 degrees south. The limbtrack maneuver will take about 48 minutes. The radio signals will be bent (refracted) as they pass through Neptune's atmosphere, and the limbtrack maneuver will control the pointing of the antenna to ensure that these



Voyager 2 will disappear behind Neptune for about 48 minutes and the spacecraft's radio signals will be refracted through the atmosphere along the planet's left limb.

signals are bent so they hit the Earth and, thus, the waiting antennas in Australia and Usuda, Japan. We will learn a great deal about Neptune's atmosphere, size, and shape from this experiment.

While Voyager 2 orchestrates its limbtrack maneuver, it will also collect fields and particles data, take infrared and ultraviolet data from Neptune's polar region, and also take a series of three wide-angle images of the ring-arc system in forward-scattered sunlight. The last of these observations will employ a new image smear reduction ploy called Maneuverless IMC (MIMC). Instead of moving the entire spacecraft smoothly to track the target, only the scan platform will be moved. Although the platform's motion is somewhat jerky, this technique will still afford clearer images than if no attempt were made to track the target.

As the spacecraft emerges from behind Neptune at N+55m 8s—again watching with the ultraviolet instrument—it will see the Earth first, followed by the Sun 49 seconds later. Voyager 2 will continue to point its antenna at Earth for the outbound ring occultation, and will take an edge-on shot of the ring-arc system as the spacecraft descends across the ring-plane at N+1.5h. For the next 20 minutes, Voyager will observe the planet's crescent limb in Neptune's southern hemisphere.

Once past Neptune and out of the planet's shadow, the spacecraft will focus more of its attention on Triton, while the high-paced routine of fields and particles data-taking continues.

About two hours past Neptune, the spacecraft will roll to a new lockstar, Alkaid, primarily to orient the charged-particle instruments for magnetospheric measurements between Neptune and Triton while, at the same time, preserving good viewing of Triton for the long-awaited upcoming observations.

For the next eight hours, Voyager will train its infrared, photopolarimetric, ultraviolet, and imaging instruments on Triton. The three highest-value imaging observations from this period promise to be among the sharpest set of pictures Voyager 2 has ever returned. Features as small as one kilometer (0.62 mile) across are expected to be resolved near the time of closest approach to Triton (N-5h15m).

By this time, Triton's small gravitational tug will be felt by Voyager, allowing scientists on Earth to measure the gravitational effects by observing changes in the radio signal. Voyager will next train its photopolarimetric and ultraviolet sensors on the star Beta Canis Majoris for about 20 minutes, watching its brightness change as it passes first through Triton's wispy atmosphere, then behind the moon, and back out again.

The ultraviolet instrument's Sun port will be pointed toward the Sun, and the spacecraft will configure its radio science equipment for another

brief Earth and Sun occultation period. For nearly forty minutes, Voyager will hold its attitude steady as it watches the two orbs of light, which wink out behind Triton for about three minutes. All of this data will be recorded onboard the spacecraft for later playback to Earth.

About 17 minutes after the Triton occultations, the spacecraft will roll back to Canopus lock, to permit unobscured viewing back towards Triton and Neptune. A thin bright sliver of sunlight will gild the limb of an otherwise dark face of Triton. The next two hours will be filled with infrared, photopolarimetric, and ultraviolet observations of Triton's disk and atmosphere. By this time, Voyager 2's tape recorder will be nearly full.

The scan platform instruments will gaze back at the Neptunian system for 31 more hours, taking more observations with its various sensors before a new set of instructions from Earth assumes control of the spacecraft. Frequent sampling of fields and particles data will continue as Voyager passes through Neptune's magnetotail.

By N+1d, the collection of data on low-energy charged particles and flow direction will slow considerably. By then the spacecraft will already be over 1.5 million km (930,000 mi) from Neptune and its velocity will have slowed to about 61,200 km/h (38,000 mi/h), only sixty percent of the speed it had just a day earlier, and only five percent faster than the speed of its eventual solar system departure.

Between N+21h and N+1d 16h, the infrared and ultraviolet instruments will scan from north to south across Neptune's unlit disk in a repetitive sequence, gathering data complementary to the inbound set of observations.

One of the big priorities following the intensive 53-hour near-encounter period will be to unload the high-value data stored in Voyager's tape recorder and send it to Earth. This will be achieved with a series of long playbacks. By four days after closest approach, two playbacks of all high-value science should be completed.

Two mosaics of the ring-arc system that will come down from Voyager 2 in these playbacks may be quite revealing, having captured the ring particles in forward-scattered sunlight. A movie of the ring arcs, much like those "filmed" during Neptune approach, will be acquired on August 28.

Various infrared, photopolarimetric, and ultraviolet maps and scans will be completed during this load as well. About midway through, visual evidence of aurorae or lightning at Triton will be sought. For about 11 hours starting at N+3d 6h, the ultraviolet instrument will search for ultraviolet emissions around Neptune's disk, to help determine the composition of escaping gases.

On August 28, the spacecraft will briefly change its lock star to Spica to allow the LECP instrument to get a better sample of the charged-particle flows in the downstream solar wind and their interaction with particles in Neptune's nearby magnetic tail. About this time, Voyager 2 should be leaving Neptune's bubble-like magnetosphere and the surrounding bowshock, heading about 40 to 45 degrees south of the ecliptic plane.

Post-encounter observations and calibrations will continue until October 2.

Update

Voyager 2's navigators cancelled the course correction planned for August 15, believing that they have already placed the spacecraft so closely on target toward Neptune that the maneuver was not needed. The final tweak to the flight path, which will occur on August 21, will place the spacecraft at its closest approach target area. The aimpoint at Neptune will determine the spacecraft's flight path past the moon Triton five hours later. Navigators are targeting for a narrow cone of space behind Triton where the Earth and Sun will be temporarily blocked from the spacecraft's view. Passage through these occultation zones is necessary for critical observations of Triton's atmosphere by the ultraviolet spectrometer and the spacecraft's radio signals.

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JPL 410-15-91 8/89

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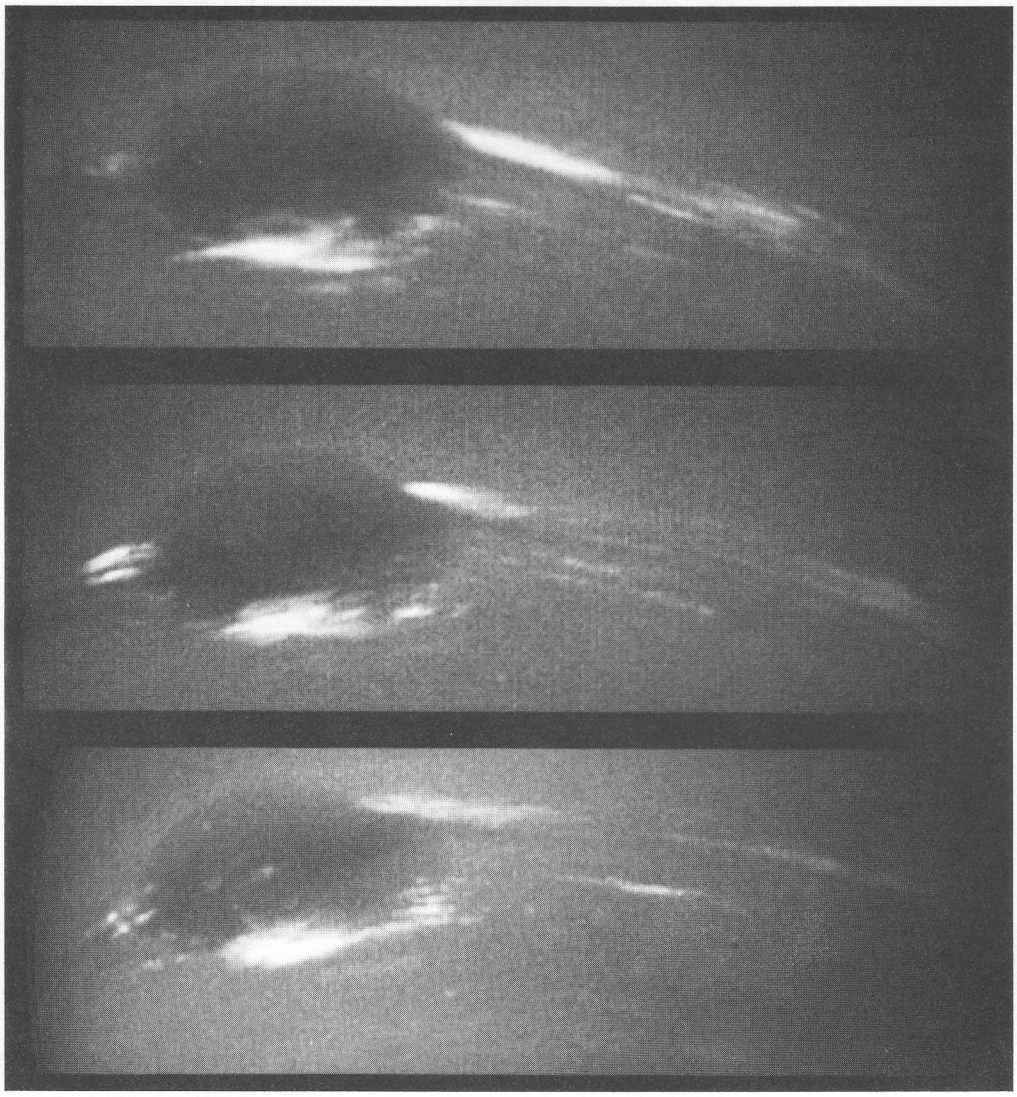
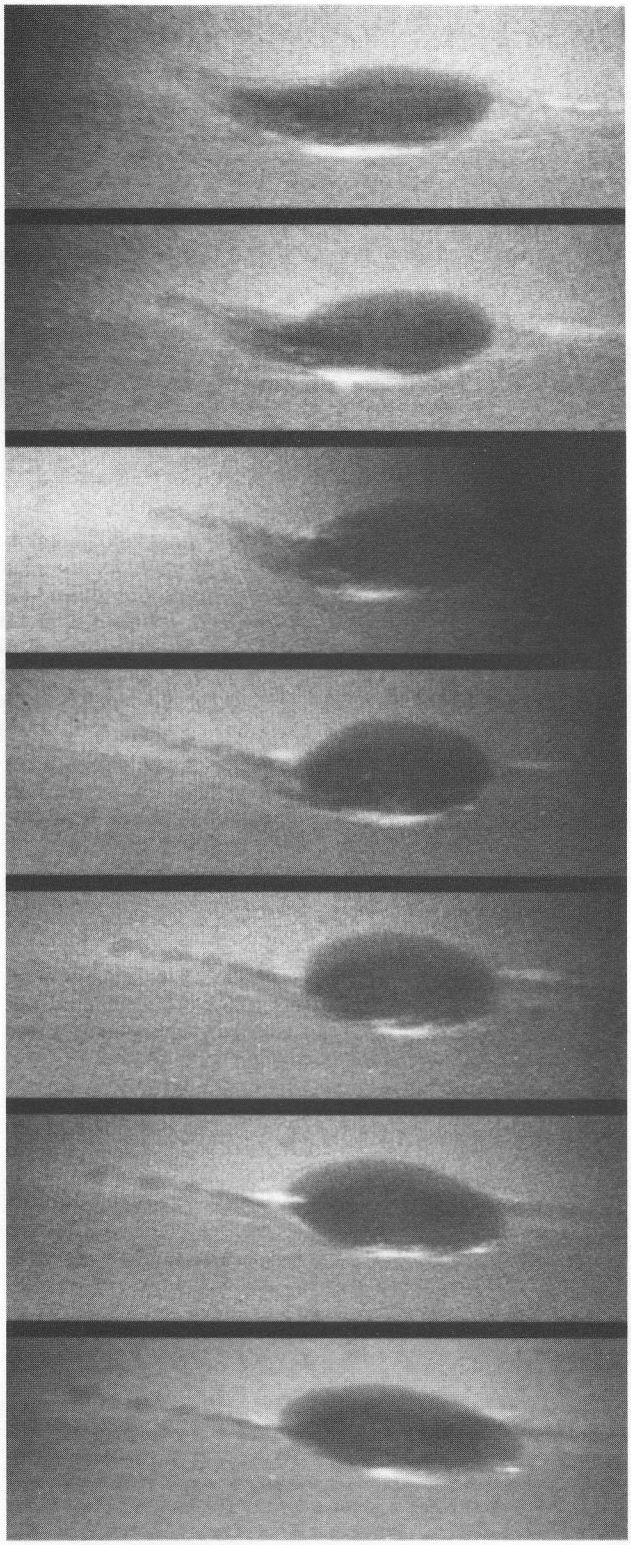
MISSION STATUS REPORT NO. 92 **AUGUST 23, 1989**



The bright cirrus-like clouds of Neptune change rapidly, often forming and dissipating over periods of several to tens of hours. (P-34622)

Cloud Evolution

In some regions, Neptune's weather is perhaps as dynamic and variable as that of the Earth. However, the scale is immense by our standards—the Earth and the Great Dark Spot (GDS) are of similar size—and in Neptune's frigid atmosphere, where temperatures are as low as 55 degrees Kelvin (-360°F), the cirrus clouds are composed of frozen methane rather than Earth's crystals of water ice.



These images show changes in the clouds around Neptune's Great Dark Spot over a four-and-one-half day period. From top to bottom the images show successive rotations of the planet—an interval of about 18 hours. (P-34610)

String of Beads . . .

Large changes can be seen in the clouds at the western end of Neptune's Great Dark Spot (GDS). A dark extension apparent in earlier images converges into an extended string of small dark spots over the next five rotations. This "string of beads" extends from the GDS at a surprisingly large angle relative to horizontal lines of constant latitude. The large bright cloud at the southern border of the GDS is a more or less permanent companion of the GDS. The apparent motion of smaller clouds at the periphery of the GDS suggests a counterclockwise rotation of the GDS—reminiscent of flow around the Great Red Spot of Jupiter's atmosphere. This activity of the GDS is surprising because the total energy flux from the Sun and from Neptune's interior is only 5 percent as large as the total energy flux on Jupiter.

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JPL 410-15-92 8/89

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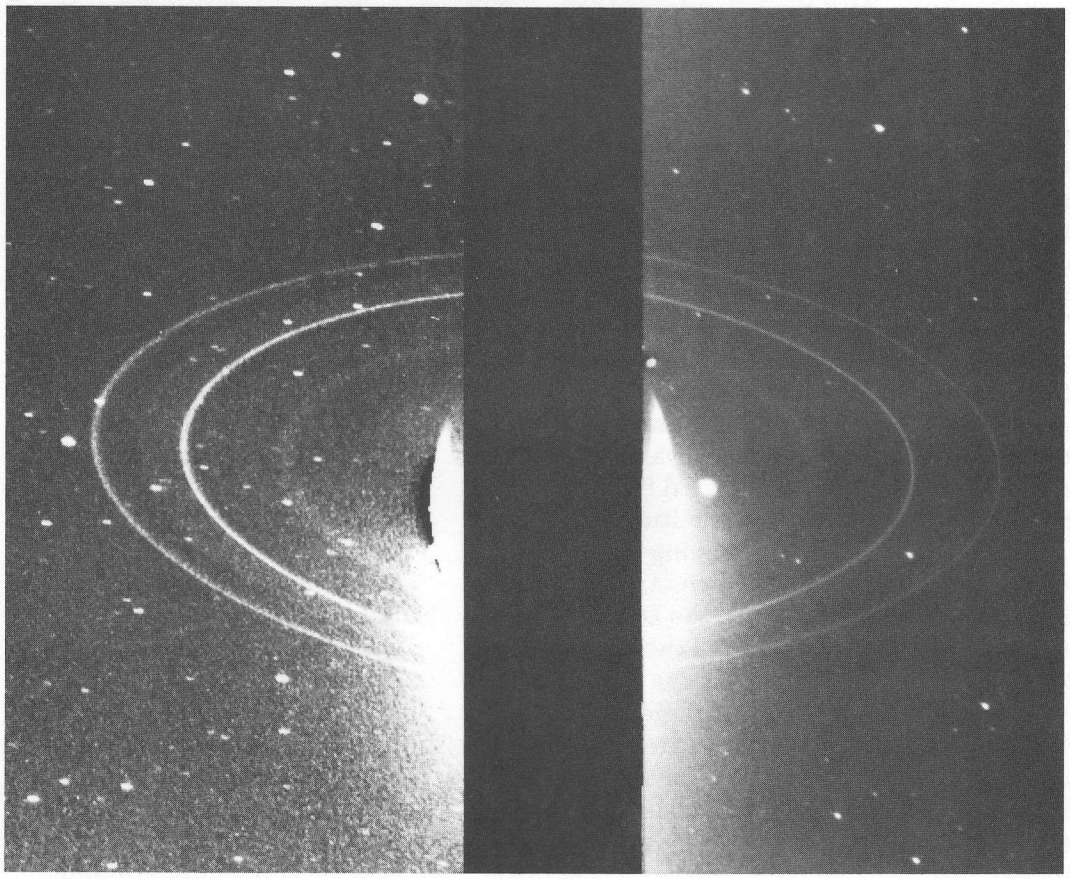
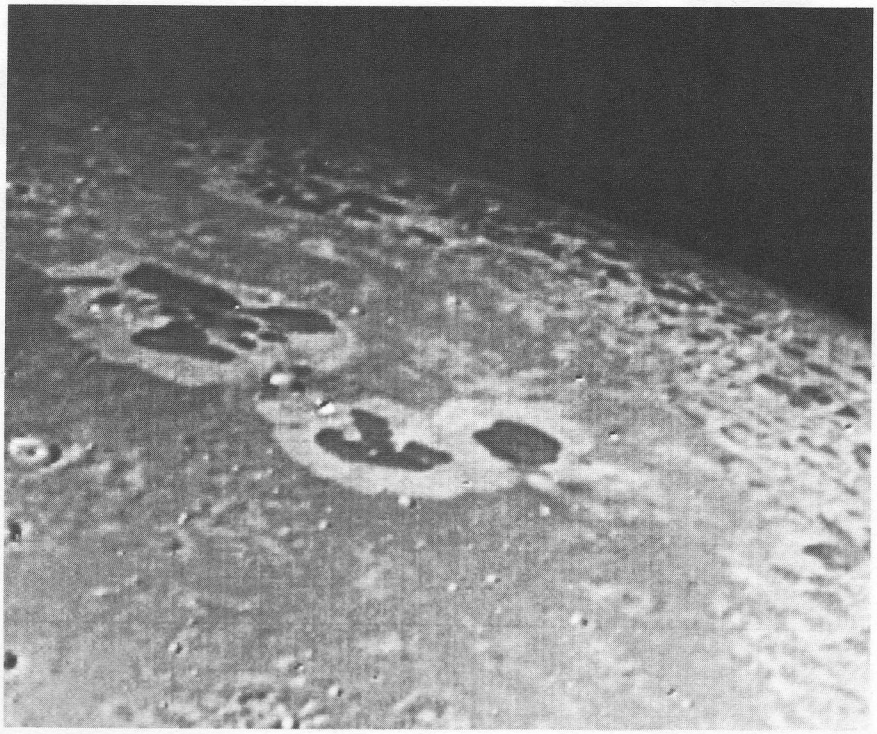


Neptune's rings are seen backlighted by the Sun in these two 591-second exposures taken August 26. (P-34726)

Three Rings, or More . . .

The ring-count at Neptune stands at three to six, depending on whether or not sheets of particles between the discrete rings are considered rings in themselves. Two images taken on August 26 from a distance of 280,000 kilometers (175,000 miles) show the two main rings plus the inner faint ring at about 42,000 kilometers (25,000 miles) from the center of Neptune, and the faint band which extends smoothly from the 53,000-kilometer (33,000-mile) ring to roughly halfway between the two bright rings. Both of these newly discovered rings are broad and much fainter than the two narrow rings. The long exposure images were taken while the rings were backlighted by the Sun at a phase angle of 135 degrees. This viewing geometry enhances the visibility of dust and allows fainter, dusty parts of the ring to be seen. A bright glare in the center is due to over-exposure of the crescent of Neptune. Two gaps in the upper part of the outer ring in one of the images are due to blemish removal in the computer processing. Numerous bright stars are evident in the background. Both bright rings have material throughout their entire orbit, and are therefore continuous.



Three irregular dark areas, surrounded by brighter material, dominate this image of a portion of Triton's surface. Low-lying material with intermediate albedo occupies the central area, and fresh craters occur along the right margin. (P-34690)

Flawless . . .

"Everything went exceedingly well and we couldn't be happier," Voyager Project Manager Norm Haynes of JPL announced on the morning after Voyager 2's fourth and final planetary encounter.

In an historic flyby witnessed by millions of people around the world, thanks to live television broadcasts of incoming images, Voyager 2 sent back extraordinary pictures of storms in Neptune's atmosphere, cloud shadows, six new moons, several new rings, and icy Triton. Voyager's fields and particles instruments discovered that Neptune's magnetic field is highly tilted, much like the case at Uranus, and other investigations pooled their knowledge to determine the composition of the atmospheres of Neptune and Triton and the structure of the rings.

Voyager 2 was designed to operate at 10 AU [astronomical units], yet its reach has been extended by a factor of three [Neptune is nearly 30 AU from the Sun) through engineering on the ground and on the spacecraft, noted Voyager Project Scientist Dr. Ed Stone of the California Institute of Technology, in seconding Mr. Haynes' commendation of the Voyager flight team, the Deep Space Network, and the affiliated tracking stations (Parkes, Australia; Very Large Array in Socorro, New Mexico; and Usuda, Japan). Voyager 2 operated where light levels were one-ninth what they are on Earth, and from a distance that made the radio signals 900 times weaker by the time they reached Earth.

Officials from Congress, NASA, and other space agencies were on hand during the week of the encounter not only to participate in the American Institute of Aeronautics and Astronautics (AIAA) conference on planetary exploration held in nearby Pasadena, but also to welcome U.S. Vice President Dan Quayle, who visited the Laboratory on August 25. Mr. Quayle is chairman of the National Space Council.

As of press time, Voyager's scientists were still awaiting playbacks of some of their data and busily analyzing what they have so far. A preliminary look at some of the most stunning results of the encounter, the amazing terrain of Triton, will be presented in future Bulletins.

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JPL 410-15-93 8/89

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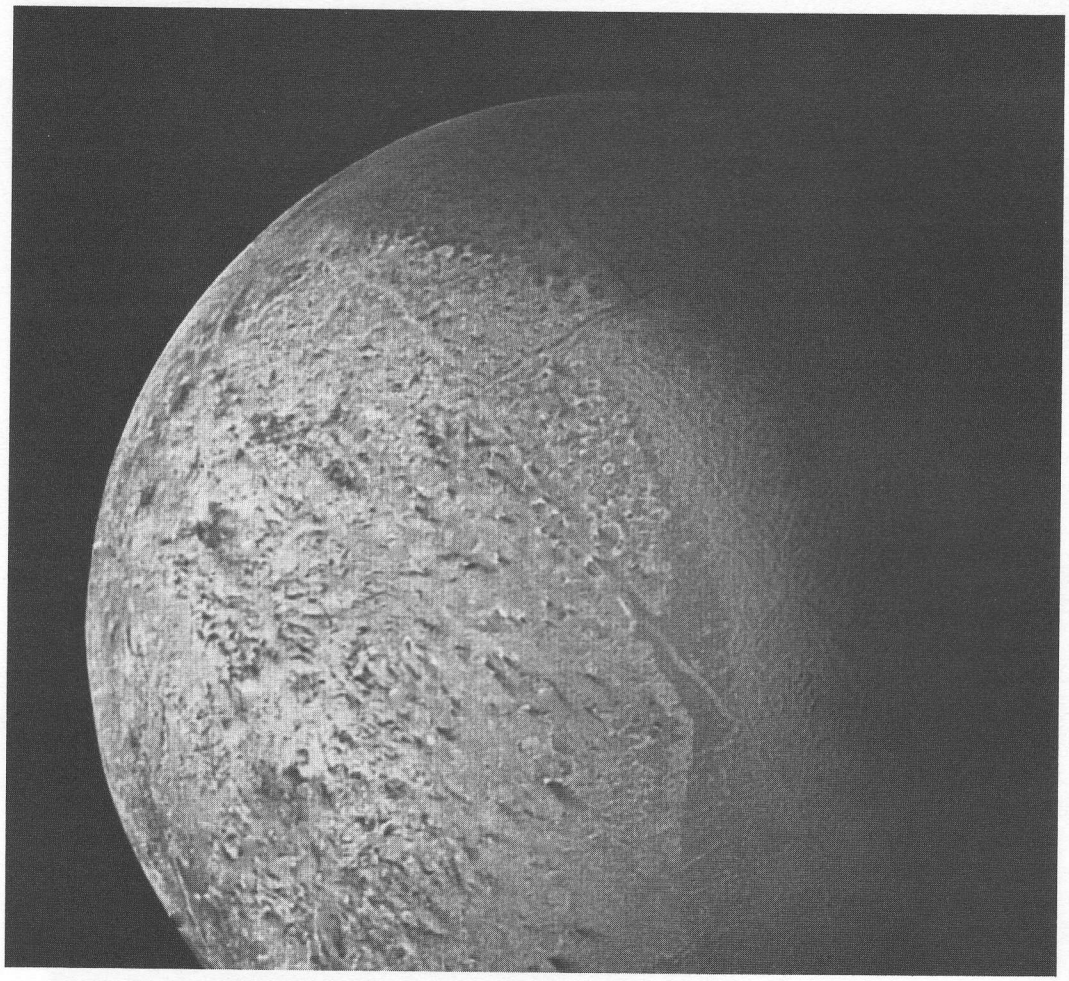
MISSION STATUS REPORT NO. 94 **AUGUST 28, 1989**



Both the darker regions to the north and the very bright subequatorial band on Triton show a complex pattern of irregular topography that somewhat resembles "fretted terrain" on parts of Venus and Mars. (P-34687)

"Imagine Jupiter orbited by Mars . . ."

—Dr. Laurence Soderblom, Deputy Team Leader, Voyager Imaging Science Team

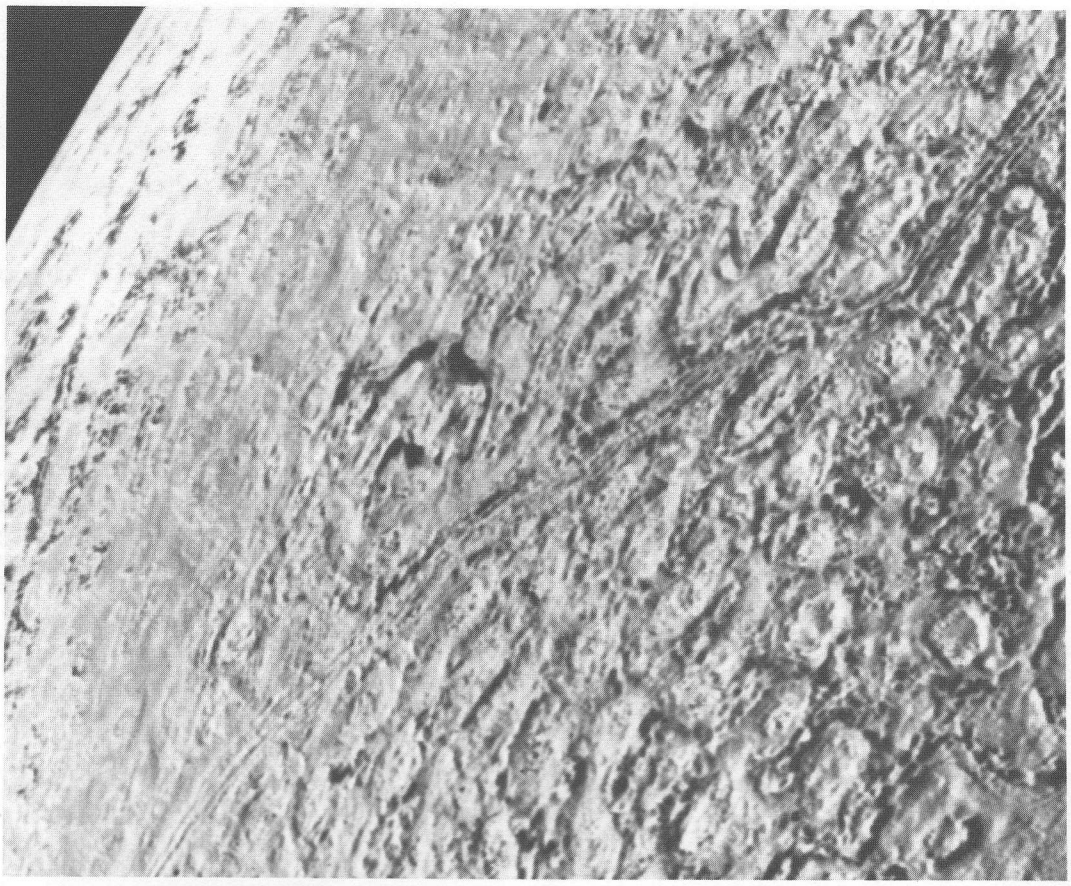
As the last solid body to be observed by Voyager 2 after a 12-year odyssey through the outer solar system, Neptune's largest moon, Triton, provided a stunning finale.

Triton's surface is marked by extraordinarily varied terrain, some of which has not been seen before on any other body, and some that is like our Moon, Mars, Io, or Europa, among several examples.

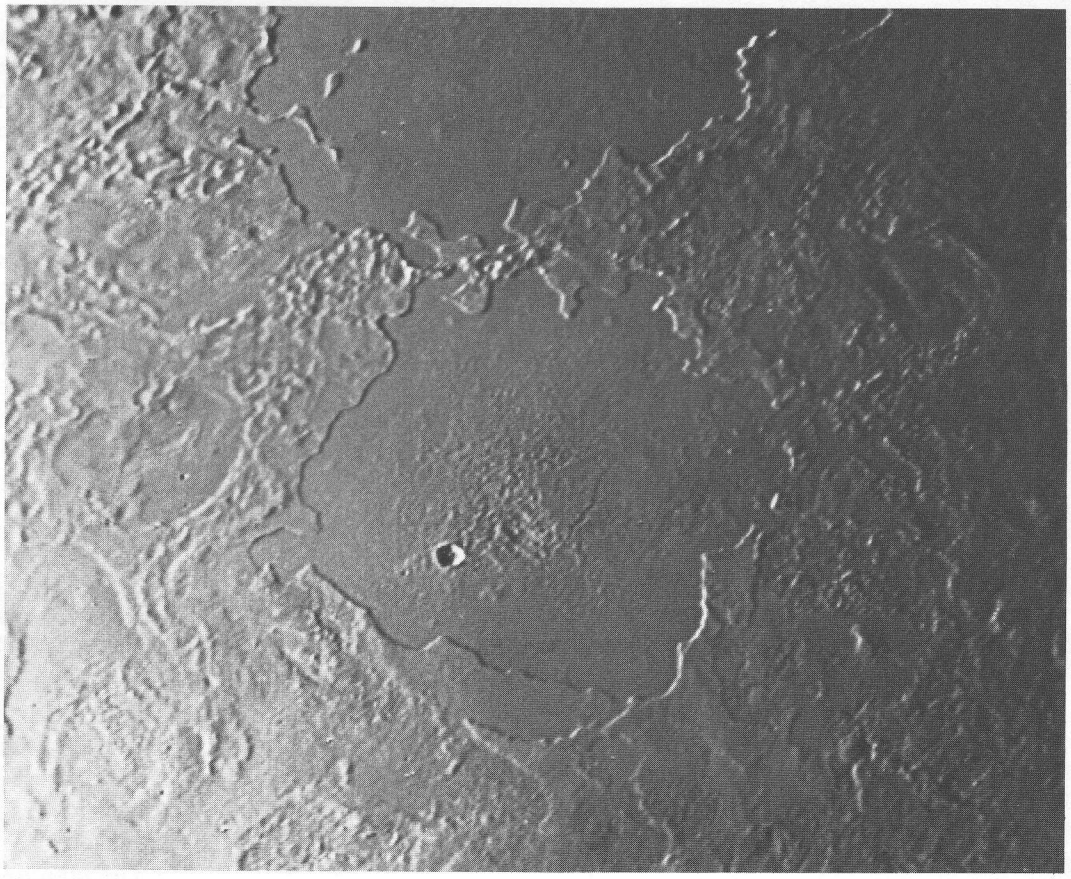
Triton has something for everybody, noted Dr. Soderblom, of the U.S. Geological Survey in Tucson, Arizona: Complex geology, polar ices, complex chemistry, and hazes. Dr. Soderblom proposes that perhaps ice volcanoes are active even now.

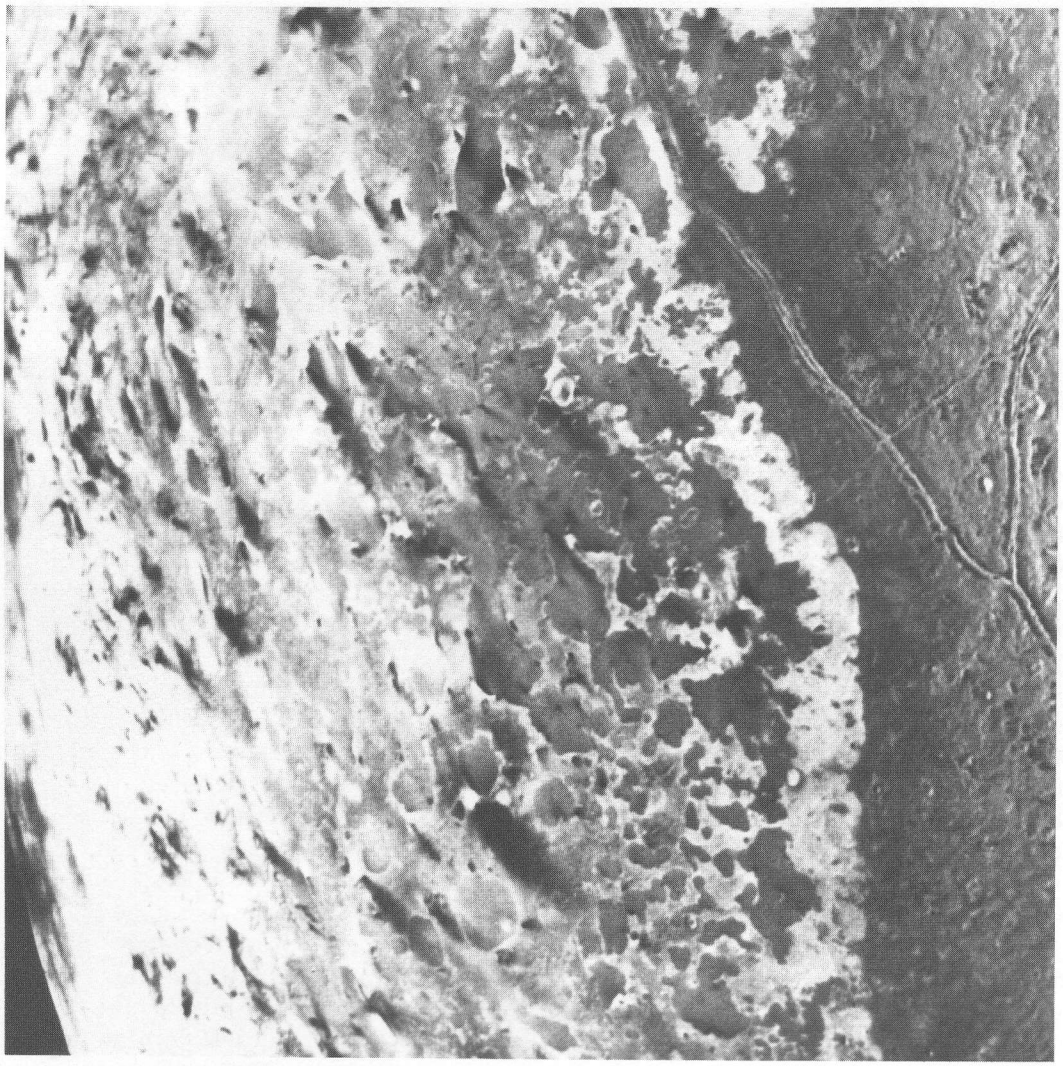
The boundary between Triton's bright southern hemi-

One of the most detailed views of the surface of Triton taken by Voyager 2 shows a peculiar landscape of roughly circular depressions separated by rugged ridges. (P-34722)



These two depressions on Triton, possibly old impact basins, have been extensively modified by flooding, melting, faulting, and collapse. (P-34692)



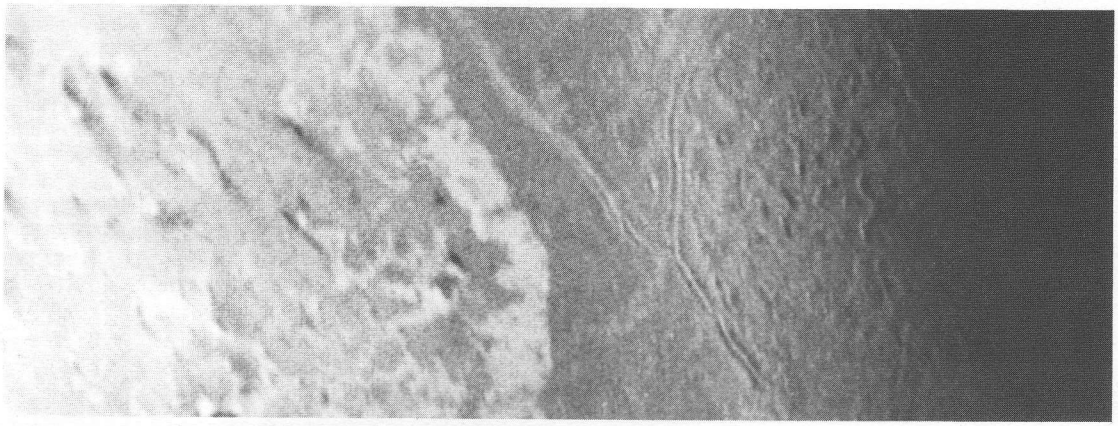


About 50 dark plumes or "wind streaks" in the south polar terrain of icy Triton may be vents where gas has erupted from beneath the surface and carried dark particles into Triton's nitrogen atmosphere. (P-34714)

sphere and the darker northern hemisphere is clearly visible (due to Triton's tilt and inclined orbit, the southern hemisphere currently receives more direct sunlight). Patterns of light and dark regions cover most of the southern hemisphere. Also evident are long, straight lines that appear to be surface expressions of internal, tectonic processes. No large impact craters are visible in the southern hemisphere, suggesting that the crust of Triton has been renewed relatively recently—that is, within the past billion years or less.

One "crazy idea" currently under study is that ice volcanoes are resurfacing the moon. About 50 dark plumes or "wind streaks" can be seen in early evaluations of images of the southern polar terrain. The plumes originate at very dark spots generally a few miles in diameter. Some are more than 100 miles long. The spots, which clearly mark the source of the dark material, may be vents where gas has erupted from beneath the surface and carried dark particles into Triton's nitrogen atmosphere. Southwesterly winds may then have transported the erupted particles, forming the gradually thinning deposits seen to the northeast of most of the vents. It is possible that the eruptions have been driven by seasonal heating of very shallow subsurface deposits of volatiles, and the winds transporting particles may be seasonal winds.

The polar terrain, upon which the dark streaks have been deposited, is a region of bright materials mottled with irregular, somewhat dark patches. The pattern of irregu-



Compositionally distinct terrain and geologic features can be seen near the boundary between Triton's lighted southern hemisphere and its shadowed northern hemisphere. (P-34720)

lar patches suggests that they may correspond to lag deposits of moderately dark material that cap the bright ice over the polar terrain.

In Triton's northern hemisphere, there are large tracts of peculiar terrain unlike anything seen elsewhere in the solar system. Most of the area is covered by roughly circular depressions separated by rugged ridges. The depressions are probably not impact craters since they are too similar in size and too regularly spaced. Their origin is currently unknown, but may involve local melting and collapse of the icy surface. A conspicuous set of grooves and ridges cuts across the landscape, indicating fracturing and deformation of Triton's surface.

Three irregular dark areas, surrounded by brighter material, may be dark substrate below a bright frost cover. Once a hole burns through the frost, for whatever reason, the region warms and defrosts, but a cold rim spreads around the area.

Other features include what appear to be frozen lakes or old calderas, which have multiple floor levels, perhaps due to massive flooding and refreezing in a sea of ice-like lava. In one scenario, fluid rises on the floor of the crater and then solidifies. The next era of melting allows the next floor to also rise and then refreeze. These types of floods are probably not localized to the caldera areas of the moon.

Triton's atmosphere has been found to be primarily nitrogen-based, with some methane. The atmosphere may extend as much as 800 kilometers (500 miles) above the surface of the 2720-kilometer (1690-mile) diameter moon. In addition, images show a thin haze layer extending 5 to 10 kilometers (3 to 6 miles) above the moon's limb. The haze may be condensation of subliming (evaporating) materials.

Topographic Textures

A false-color map of Triton shows several compositionally distinct terrain and geologic features. At center is a gray-blue unit referred to as "cantaloupe" terrain because of its unusual topographic texture. The unit appears to predate other units to the left. Immediately adjacent to the cantaloupe terrain is a smoother unit, represented by a reddish color, that has been dissected by a prominent fault system. This unit apparently overlies a much-higher-albedo material, seen farther left. A prominent angular albedo boundary separates relatively undisturbed smooth terrain from irregular patches that have been derived from breakup of the same material. Also visible at the far left are diffuse, elongated streaks, which seem to emanate from circular, often bright-centered features. The parallel streaks may represent vented particulate materials blown in the same direction by winds in Triton's thin atmosphere.

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JPL 410-15-94 8/89

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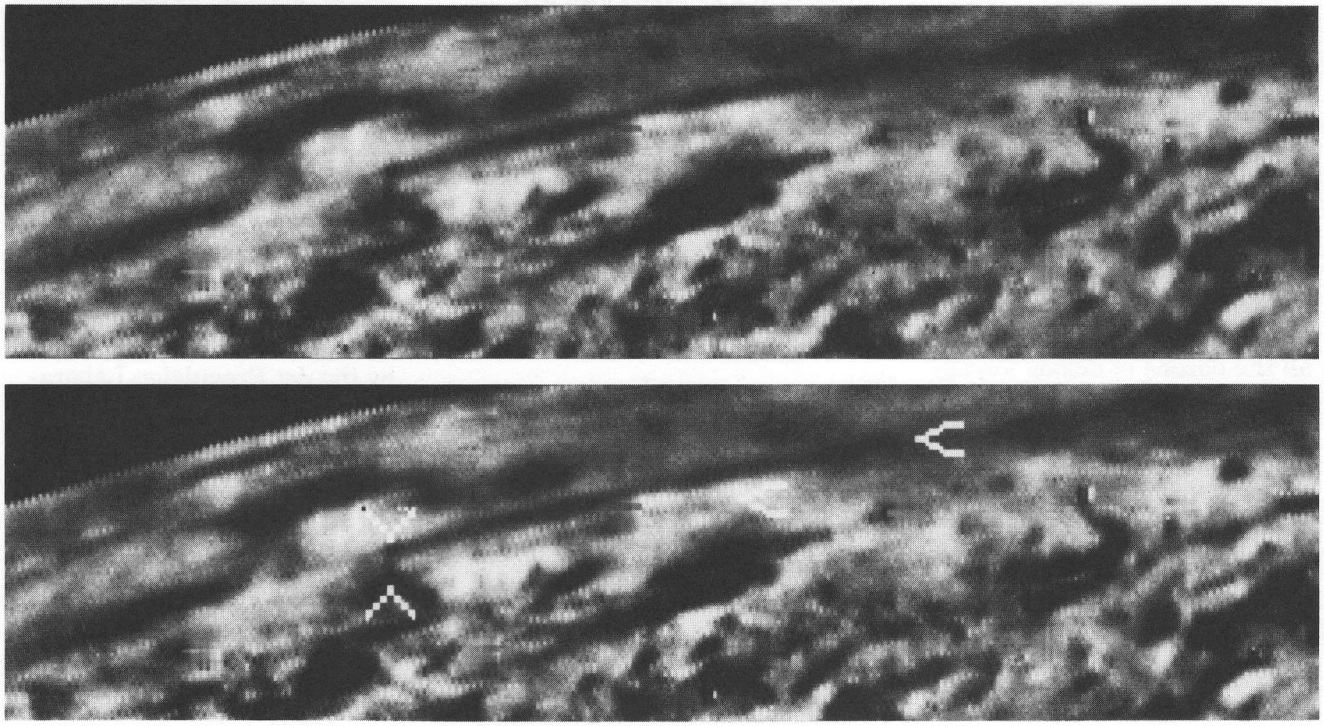

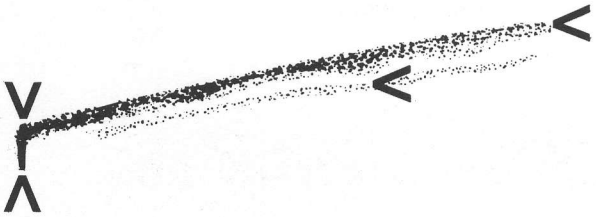

A geyser-like eruption of dark material shoots several kilometers straight up from the surface of Triton, forming a cloud that drifts 150 kilometers westward. (The same image is shown in both panels; the lower panel is marked to indicate the top and bottom of the plume, the extent of the cloud, and the visible extent of the cloud's shadow.) (P-34940)

Triton Geyser Is a Corker!

A five-mile-tall, geyser-like plume of dark material has been discovered erupting from the surface of Neptune's cold moon Triton in images returned last month by Voyager 2.

The discovery comes just as the Neptune encounter—Voyager 2's fourth and final planetary flyby in 12 years—officially ends today, October 2.

This is the first time geyser-like phenomena have been seen on any solar system object, other than Earth, since Voyager 1 discovered eight active geysers shooting sulfur above the surface of Jupiter's moon Io in 1979. The new finding augments Triton's emerging reputation as the most perplexing of all the dozens of moons Voyagers 1 and 2 have explored. Surface temperatures on Triton have been measured to be about -390°F, and the terrain is among the most varied seen anywhere else in the solar system.

Voyager 2's camera captured the eruption shooting dark particles high into Triton's thin atmosphere. Resembling a smokestack, the narrow stem of the dark plume, measured using stereo images, rises vertically nearly eight kilometers (five miles) and forms a cloud that drifts 150 kilometers (90 miles) westward in Triton's winds.

While Voyager scientists are trying to determine the mechanism responsible for the eruption, one possibility being considered is that pressurized gas, probably nitrogen, rises from beneath the surface and carries aloft dark particles and possibly ice crystals. Whatever the cause, the plume takes the particles to an altitude where they are left suspended to form a cloud that drifts westward.

The dark plume was first discovered in stereo images taken by Voyager 2. The image reproduced here was taken on August 24 from a distance of 99,920 kilometers (approximately 62,000 miles). The image shows the geyser-like column nearly in profile, since the spacecraft was only 16 degrees above the horizon as seen from Triton's surface at the base of the plume.

Voyager 2's working life among the planets may be at an end, but the spacecraft and its twin, Voyager 1, are expected to continue returning information about the various fields and particles they encounter while approaching and eventually crossing the boundary of our solar system. The plutonium-based generators that provide electricity to the spacecraft are expected to keep alive the computers, science instruments, and radio transmitter for up to 25 or 30 more years.

As of today, the long-lived project will now be known as the Voyager Interstellar Mission.

The Voyager Project is managed for NASA's Office of Space Science and Applications by the Jet Propulsion Laboratory.

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National Aeronautics and Space Administration

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Pasadena, California

JPL 410-15-95 10/89

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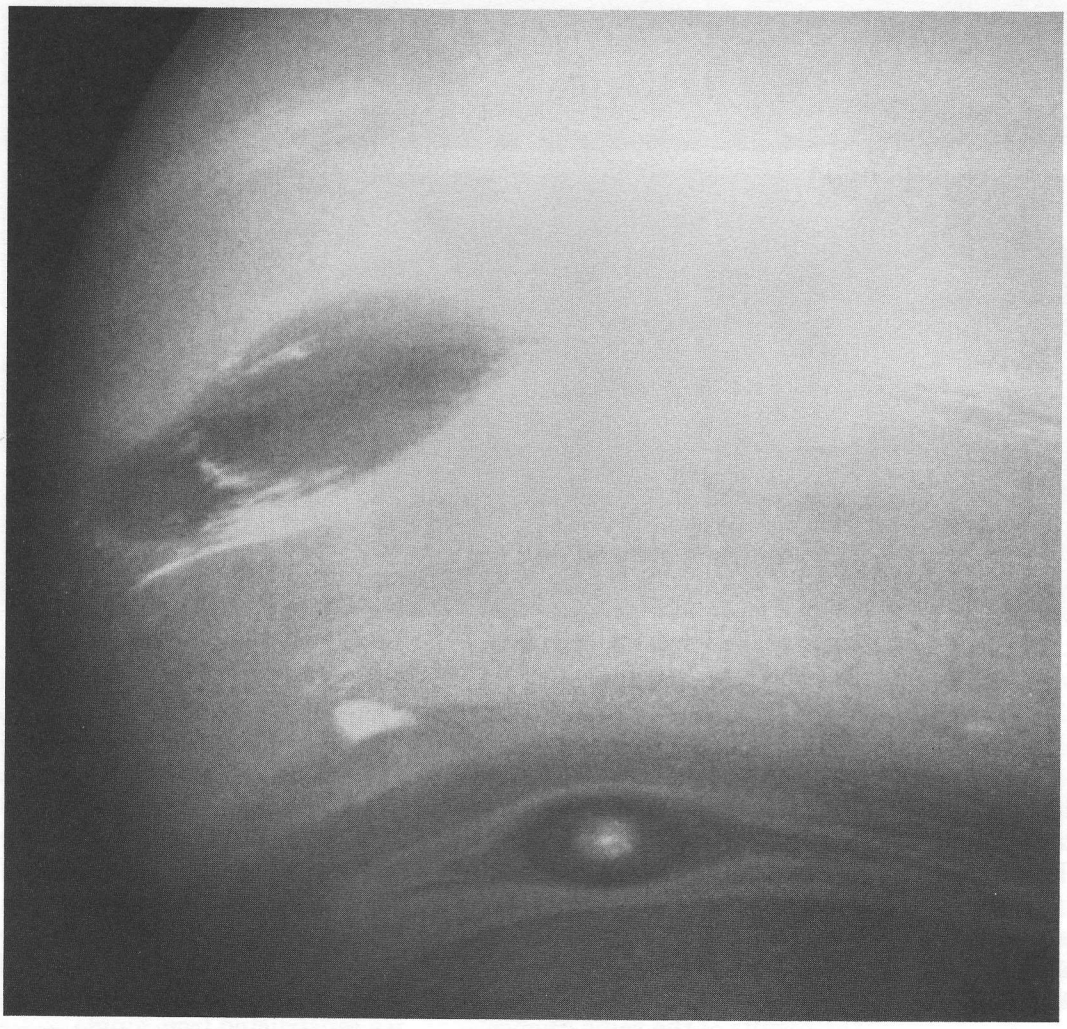
MISSION STATUS REPORT NO. 96 **OCTOBER 4, 1989**

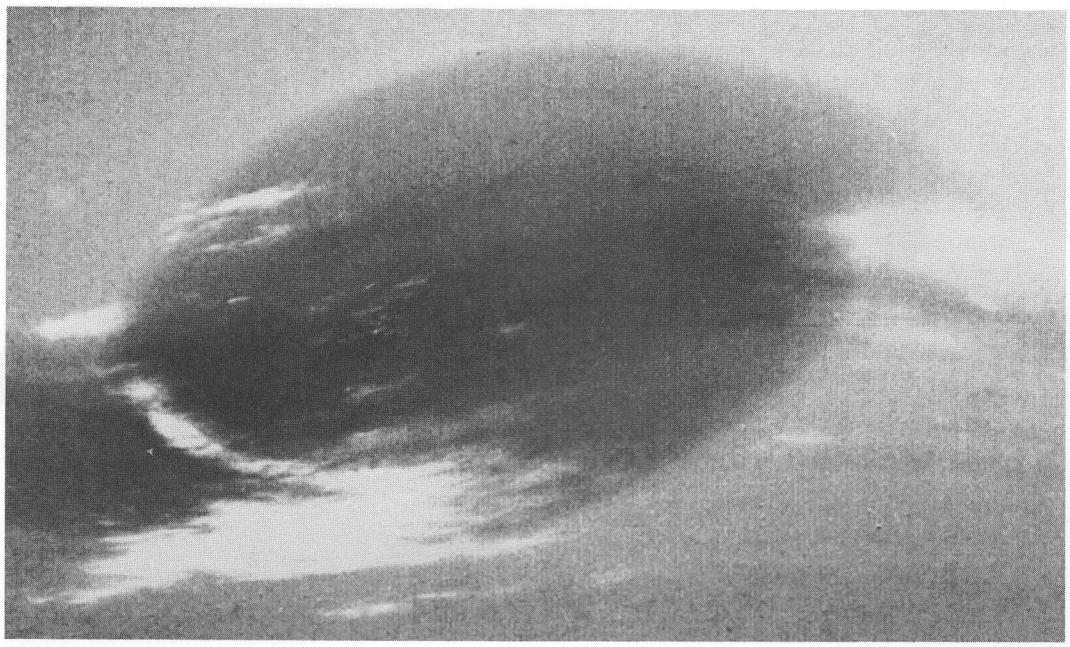


Neptune's three most prominent features—the Great Dark Spot, the bright Scooter, and Dark Spot 2 with its bright core—move at different velocities and only occasionally appear close to each other as seen here. (P-34648)

"You have earned the highest marks for making the solar system intelligible to the world at large in a most meaningful way. The integrity of the program and its participants was manifest to the world; we are all extremely proud of it.

I salute the entire Voyager team from first to last for such a significant and permanent positive addition to human knowledge and human horizon. This was the kind of excitement that counts. Well done!"

Richard H. Truly
Administrator, NASA



The pinwheel (spiral) structure of both the dark boundary and the white cirrus suggest that the Great Dark Spot is a storm system rotating counterclockwise. (P-34672)

Neptunian Meteorology

With the completion of Voyager 2's grand tour of the outer planets, Neptune "the mystic"* has at last yielded some of its long-kept secrets.

Prior to Voyager 2's visit we didn't know even basic information about the fourth giant planet, such as the length of its day or whether it had a magnetic field. While analysis of Voyager's data continues, a summary of the quick-look results will be given here.

Although Neptune receives only 1/900th as much energy from the Sun as the Earth does, it reemits about three times this amount—an indication that heat is being generated in Neptune's interior and radiated to space. Scientists have long thought that the winds in a planet's cloud tops are driven by the Sun's heat, but now they must consider more strongly the contributions of the planet's own interior heat source.

Voyager's infrared observations of Neptune showed that temperatures are warmer near the equator and south pole, and cooler in mid-latitudes—surprisingly similar to the case at Uranus. Since the south pole is tilted slightly toward the Sun at this point in Neptune's orbit, it is not surprising that it is warm. But the warmth at the equator is surprising because less sunlight falls there due to the planet's tilt. Voyager's ultraviolet investigation measured temperatures at high altitudes in Neptune's stratosphere at about 400 kelvins (250°F), while the infrared investigation measured the temperature at the 100 millibar pressure level to be about 55 kelvins (–360°F).

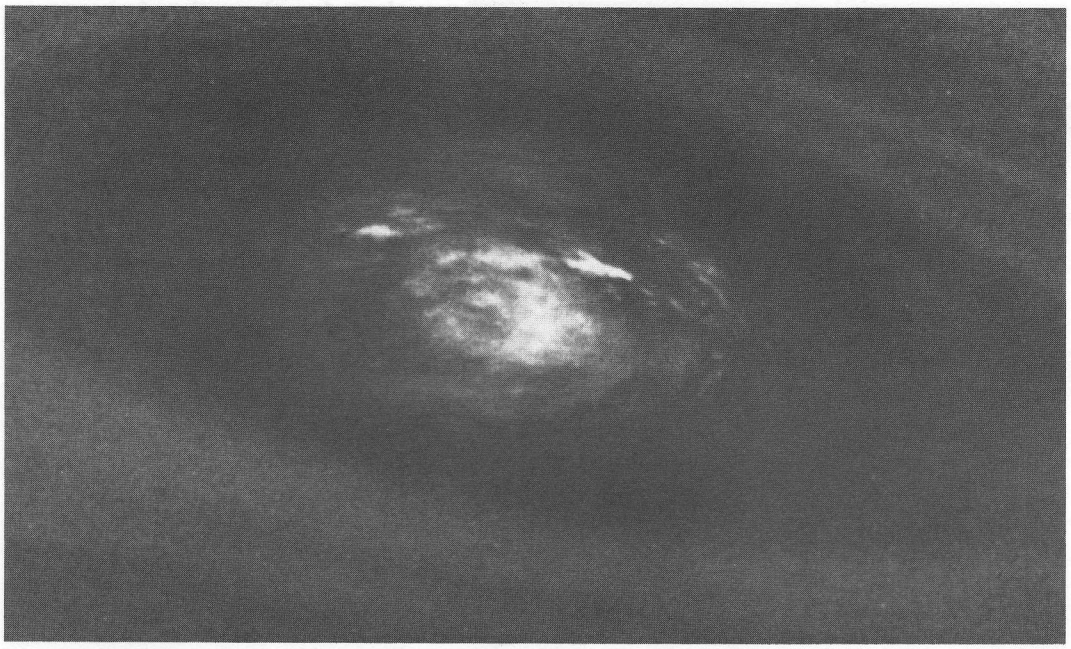
While analysis continues, the results of the radio science investigation seem consistent with an atmospheric chemical composition of about 85 percent molecular hydrogen, 13 percent helium, and 2 percent methane. The infrared investigation's results indicate that some amount of acetylene exists as well.

Neptune is the densest of the four giant planets, about 64 percent heavier than if it were composed entirely of water.

Hints of cloud systems had been observed from Earth-based telescopes for the past several years, but only when Voyager arrived could we discover that Neptune is banded and has a number of dark spots, bright spots, and cirrus clouds. As on other planets, wind shears occur at the boundaries between eastward and westward bands.

The Great Dark Spot, at about 22 degrees south latitude, is probably at lower altitude than its accompanying bright clouds. The size of the Great Dark Spot in its east–west extent is comparable to the diameter of the Earth—over 12,500 kilometers (nearly 8,000 miles). Time-lapsed movies constructed from single frames show that the Great Dark Spot is not totally oval, has spiral arms, and appears to have a counterclockwise circulation pattern. Imaging scientist Dr. Andy Ingersoll of Cal-

*From Gustav Holst's symphony, *The Planets*.



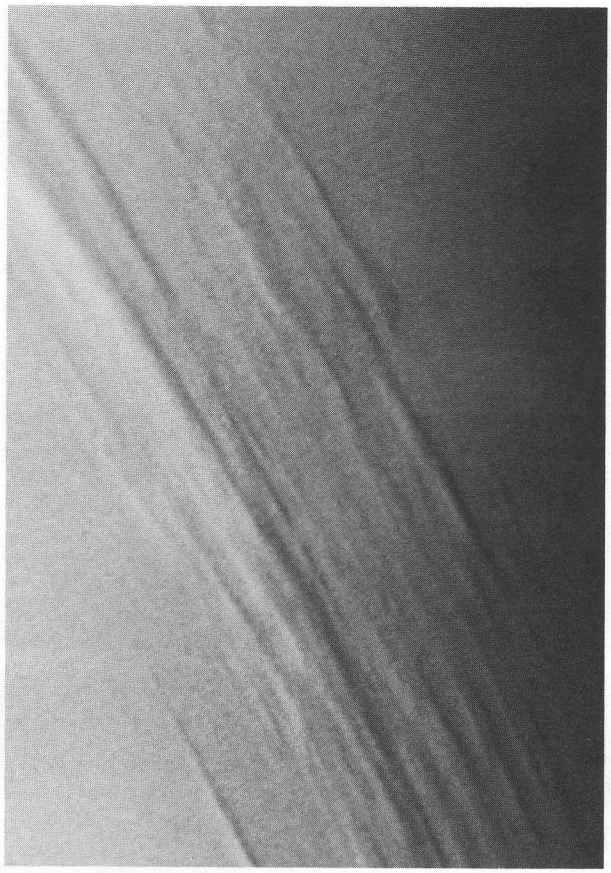
Banding surrounding Dark Spot 2 indicates unseen strong winds, while structures within the bright spot suggest both active upwelling of clouds and rotation about the center. (P-34749)

A cylindrical projection view of Neptune ranges from 80 degrees south of the equator to 30 degrees north and shows the large storms and wave patterns stretching around the planet. (P-34630)

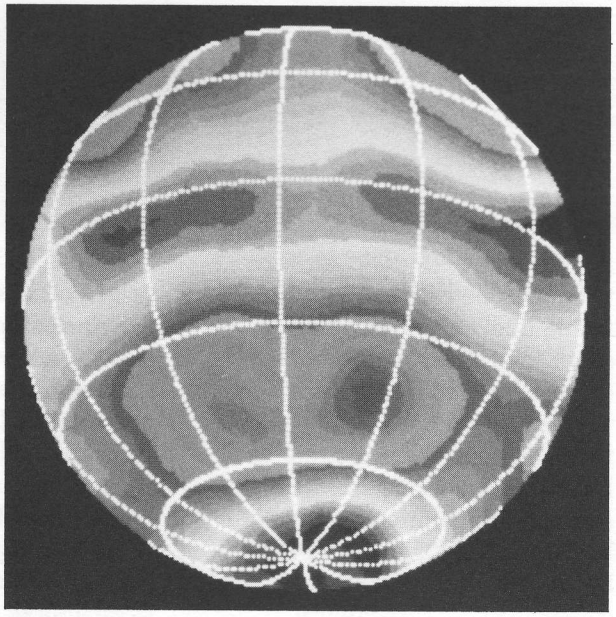
tech drew chuckles with the remark that the Great Dark Spot looks like "a great glob of pizza dough going around." The Great Dark Spot circles Neptune in a little less than 18 hours, implying that it is in an atmospheric zone with westward (retrograde) winds of more than 300 meters per second (700 miles per hour!). Bright, wispy, "cirrus-type" clouds overlie the Great Dark Spot at its southern and northeastern boundaries.

According to atmospheric scientist Dr. Jim Pollack of NASA's Ames Research Center, some of the bright spots on Neptune may be convective clouds rising above the base of the methane clouds. He suggests a cycle of methane on Neptune wherein ultraviolet sunlight first converts methane to hydrocarbons in the stratosphere. The major hydrocarbons, such as ethane and acetylene, then drift down to the colder lower stratosphere, where they evaporate and condense into hydrocarbon ices. These ice particles fall into the warm troposphere, evaporate, and are converted back to methane. The methane is returned to the stratosphere by buoyant convective methane clouds, which rise to the base of the stratosphere or higher. The bright central core of the southern dark spot is probably such a rising convective cloud, and the bright cloud at about 42 degrees south latitude may be interpreted as a cloud plume rising between the methane and hydrogen sulfide cloud decks.

As Voyager 2 approached the planet, imaging scientists were able to track the features in the clouds to determine the wind speeds. They were surprised to find that some features, such as the Great Dark Spot, had a rotation period of 18 hours, in close agreement with ground-based observa-



High, bright cloud streaks cast shadows on cloud decks as much as 50 kilometers (30 miles) below them. The cloud streaks are 50 to 200 kilometers (30 to 125 miles) in width, while the shadows are 30 to 50 kilometers (20 to 30 miles) in width. (P-34709)



An infrared map of brightness temperatures shows that Neptune is warmer near the equator and south pole and cooler in the mid-latitudes. (JPL 12391AC)

tions, but that other features moved much faster. The bright cloud at about 42 degrees south latitude was nicknamed "Scooter" because of its 16-hour rotation period. However, motions in the atmosphere are indicative only of wind speeds. The rotation of the bulk of the planet can best be measured by studying the periodicity of the planet's radio signals, generated by deep-seated convection currents in the planet's interior, and carried to space along the planet's magnetic field lines. The Planetary Radio Astronomy Team, led by Dr. Jim Warwick of Radiophysics, Inc., determined from Neptune's radio signals that a Neptunian day is 16 hours 3 minutes.

Dr. Brad Smith, leader of Voyager's Imaging Science Team, suggests that the clouds near the Great Dark Spot are not moving rapidly themselves, but that the air around them is, analogous to lenticular clouds that form over mountains here on Earth. As winds go through the region, they are deflected upward where the volatiles condense out and form clouds.

Voyager also saw cloud shadows in Neptune's south polar region, the first time a Voyager spacecraft has been able to see such features on any planet. The shadows are cast by methane cirrus-like clouds that are estimated to be 50 to 75 kilometers (30 to 45 miles) above the haze or stratus clouds.

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JPL 410-15-96 10/89

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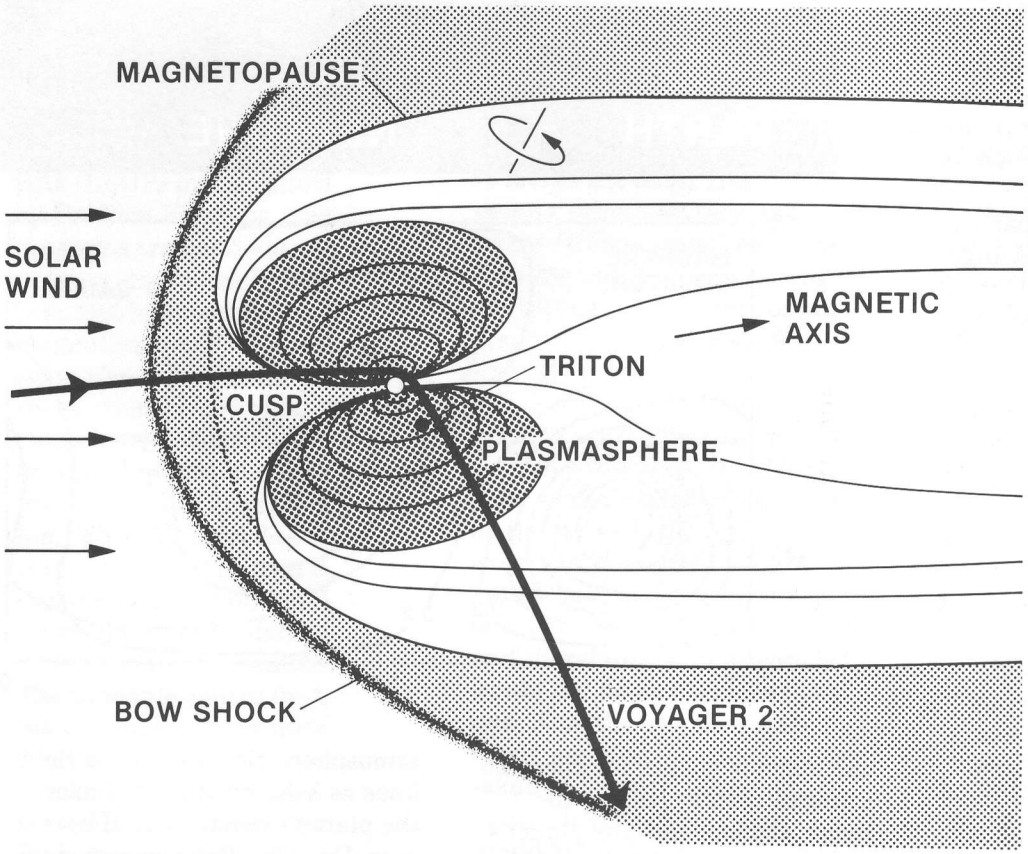
MISSION STATUS REPORT NO. 97 **OCTOBER 16, 1989**

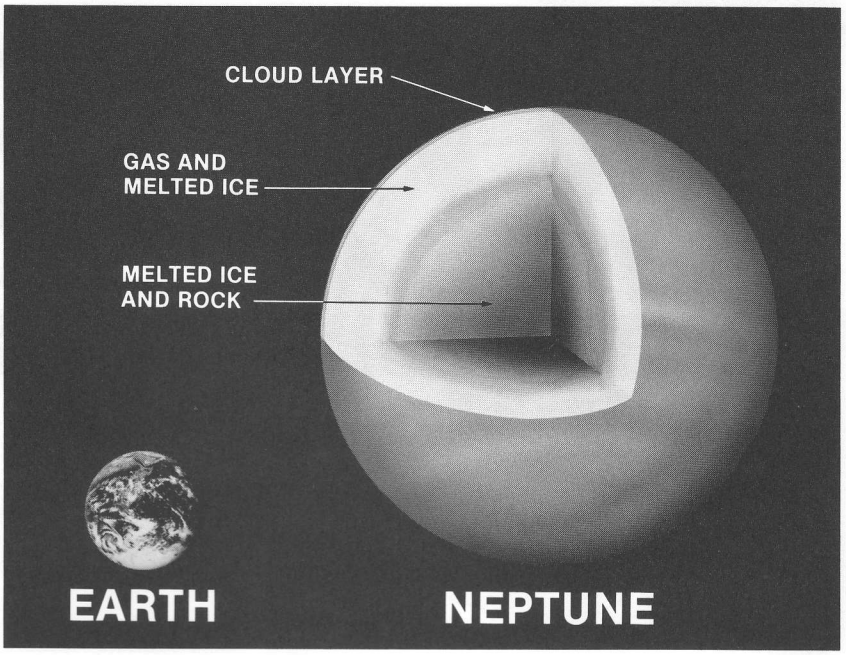


As Voyager 2 left the solar wind, the spacecraft passed through a relatively high-latitude cusp of Neptune's plasma domain before passing into a more nearly equatorial region of the tilted and offset magnetosphere. (JPL 12355AC)

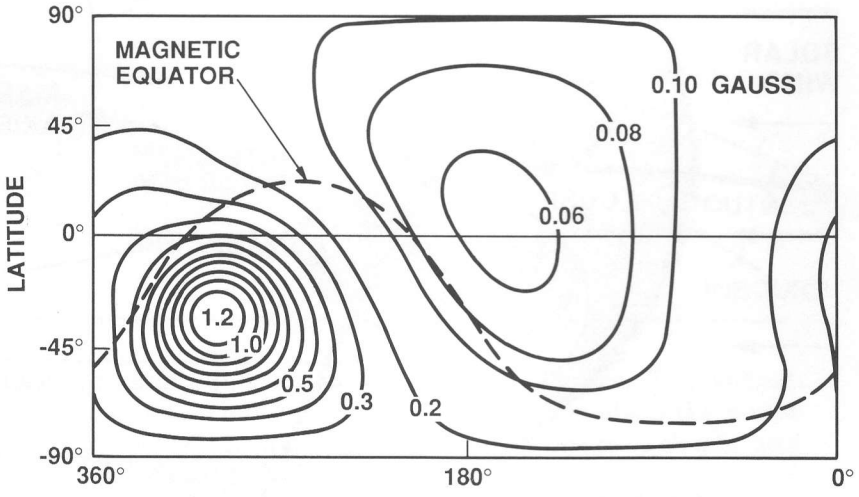
Magnetically, Neptune Is Much Like Uranus

As Voyager 2 closed on Neptune, the bets were that Neptune would have a simple magnetic dipole roughly aligned with the planet's rotational axis and centered within the planet.

Six of Voyager's instruments measure fields and particles. The first of these to sense the planet is usually the planetary radio astronomy (PRA) subsystem, which detects planetary radio emissions. These radio signals result from dynamo electrical currents generated deep in a planet's interior and carried to space along the planet's magnetic field lines. Charged particles near the planet are trapped within an imaginary "cage" formed by the magnetic field lines and are swept along as the planet rotates. All seemed quiet in the fields and particles domain until August 17 (PDT) when the PRA began to detect radio signals from Neptune. From the intervals between the signals, the PRA team deduced that the



Dynamo electrical currents are probably generated in Neptune's gas and melted ice layer as the planet rotates, producing a magnetic field that is quite near the "surface" in some regions, and ranging in strength from 1.2 to 0.06 gauss. (Top: JPL 12266BC; Below: JPL 12387AC)



rotation rate of the bulk of the planet is about 16 hours—much shorter than the 18-hour period deduced from tracking cloud features in the atmosphere.

The next fields and particles event, the bow shock crossing, occurred on August 24. During interplanetary cruise, the spacecraft is in the solar wind where particles travel at supersonic speeds near one million miles per hour. At the bow shock, the solar wind flow is slowed to subsonic speeds, heated, and deflected by interaction with the planet's magnetic field. Prior to crossing the Neptune bow shock approximately 35 Neptunian radii from the planet's center (about 865,000 kilometers or 537,000 miles), measurements by the plasma science instrument indicated that the solar wind temperature was 6,300 kelvins, but the density was only 0.0045 protons per cubic centimeter.

Within the magnetosheath, the temperature rose dramatically to about 250,000 kelvins and the density to 0.03 protons per cubic centimeter. Inbound to Neptune, Voyager 2 was in the magnetosheath for about 25 minutes before crossing the magnetopause into the planet's magnetosphere at about 22 Neptunian radii (about 500,000 kilometers or 300,000 miles) from the planet's center.

The magnetic field did not behave as expected, nor was it even *where* it was expected. Expecting a magnetic axis roughly aligned with the rotational axis, the fields and particles investigations were geared for an unusual opportunity to directly detect particles spiraling into Neptune's north polar atmosphere along magnetic field lines as Voyager 2 passed near the planet's north pole. However, Dr. John Belcher, principal investigator for Voyager's plasma science investigation, announced on August 25 that from their data, his team inferred a magnetic dipole tilted 50° from the rotational axis—surprisingly similar to the 59° tilt of Uranus' dipole. (Earth's dipole is tilted 11° from the rotational axis.)

Rather than the expected crossing near the confluence of the magnetic field lines, Voyager 2's path had carried it for the first time through a relatively high-latitude cusp of a planetary plasma domain and then into a more nearly equatorial region of the magnetosphere, allowing observations within the magnetosphere for about one-and-a-half planetary rotations.

In addition, Dr. Norm Ness, principal investigator for the magnetometry investigation, reported that Neptune's field is not a simple dipole. (An example of a simple dipole is a child's bar magnet.)

The low-energy charged particle (LECP) investigators, led by Dr. Tom Krimigis, reported sensing a tremendous number of protons, as well as helium, carbon, and hydrogen in Neptune's magnetosphere. The LECP team also reported that in the range from 28,000 to 43,000 electronvolts, they found an increased population of energetic protons inside the orbit of Triton. They measured temperatures about 700 million degrees Celsius (over 1.3 billion degrees Fahrenheit) and a density of 0.00025 per cubic centimeter. The probable source for these hot plasmas is Neptune's ionosphere.

The LECP team also reported that Voyager 2 had passed over a magnetic polar area after all, yielding the first direct detection of auroral zone particles impacting the atmosphere of a nonterrestrial planet. Their initial estimates of the auroral power was greater than one million watts (Earth's auroral power, which we see as the Northern or Southern Lights, is about 100 billion watts). Because of the tilt and offset of the magnetic field, Neptunian auroras might be expected to occur near the equator rather than at the poles, but because of the complex structure of the magnetic field near the planet, auroral activity is probably widespread.

In summary, the quick-look analysis of Voyager's pass through Neptune's magnetosphere indicates that Neptune looks very much like Uranus, magnetically. The dipole is tilted 50° from the rotational axis, and magnetic north is in the southern hemisphere. In addition, the magnetic pole is offset from the center of the planet by 2/5 (0.4) of Neptune's radius (Uranus's magnetic pole is offset by 1/3 [0.3] Uranian radius.) The magnetosphere undergoes dramatic changes as the planet rotates and the moons orbit. The dipole moment (the mean field strength at the 1-bar pressure level) is 0.13 gauss R_N3, but because of the large offset the strength of the field ranges from 1.2 to 0.06 gauss (Earth's surface field is about 0.3 Gauss). The large variation in field intensities indicates that dynamo electrical currents may be much closer to the "surface" (the 1-bar pressure level) of Neptune than was true for Jupiter or Saturn.

In terms of the density of charged particles in the planet's magnetosphere, Voyager's magnetosphere is the emptiest encountered by Voyager. The large tilt and offset apparently allow the satellites and ring particles to efficiently "sweep" charged particles out of the magnetosphere.

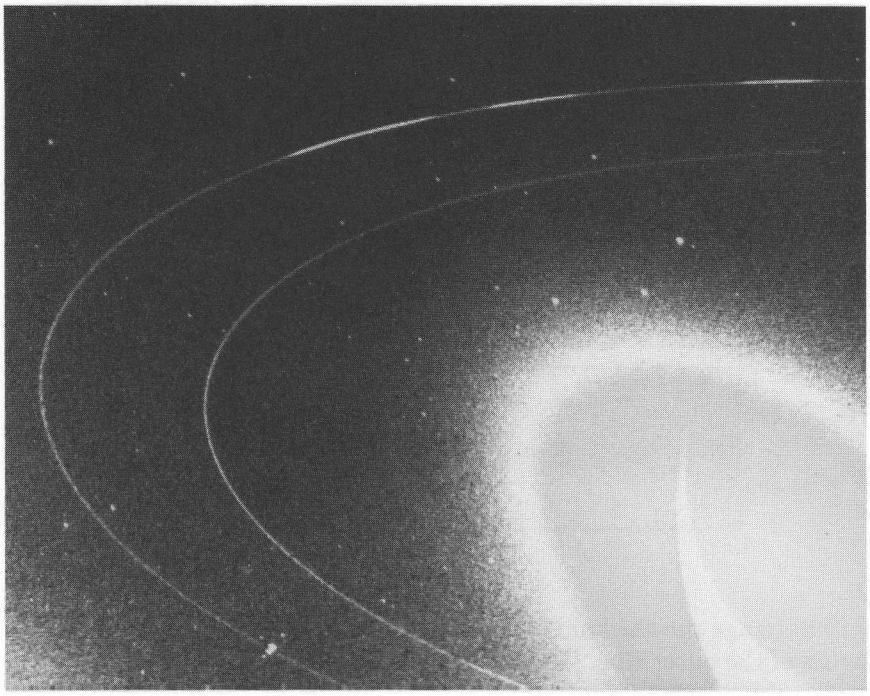
The Rings Are Complete, Not Just Arcs

Another Neptunian mystery unraveled in late August when Voyager scientists confirmed that Neptune does indeed have complete rings, not just ring arcs.

A number of ground-based observations over the last few years had produced a confusing set of data. While observing stellar occultations, in which a distant star appears to pass behind a planet, astronomers noted that, a number of times, the starlight briefly dimmed on one side of Neptune but not on the other. If these stellar occultations were caused by ring material passing in front of the star as viewed from Earth, one would expect the occultation to occur on both sides of the planet, but it never did, even in instances when two observatories recorded the same event. To account for these odd circumstances, scientists formulated a theory of partial rings, or ring arcs, that did not completely circle the planet.

Interpretation of some of the ring arc observations was difficult because Neptune's position could not be determined precisely enough. In addition, the degree of Neptune's axial tilt was not known to within 1°. For ground-based astronomers, these small uncertainties enormously complicated their understanding of the ring arc locations.

In early August, a number of excited phone calls were made in the middle of the night when a

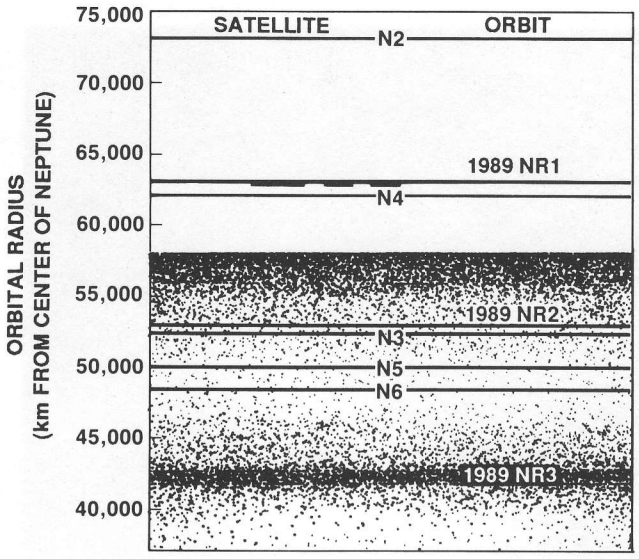


Neptune's two main rings are seen backlit by the Sun, and three bright features, each about 6 to 8° long, are seen at top in the outer ring. The image of the planet was greatly overexposed to capture detail in the rings. (P-34712)

series of Voyager images unmistakably showed arcs of ring material about 54,000 and 62,000 kilometers (about 34,000 and 39,000 miles, respectively) from the center of the planet. The inner of the two arcs spanned about 10° of arc, while the outer arc spanned about 45°, and seemed to have three or four segments. The bigger arc was whimsically nicknamed the "Arc de Triomphe."

To the team's dismay, however, the shorter arc could not be found in subsequent images, and was dubbed "the lost arc." But on August 22, a smiling Dr. Brad Smith, leader of Voyager's Imaging Science Team, announced to the press that not only had the lost arc been found, it was not an arc. "It goes all the way around," he beamed. The ring was continuous but of a very low optical thickness, too faint to have been detected from Earth. The outer ring was also seen to be continuous, but only three thicker segments could have been detected from Earth and were apparently responsible for all the reported occultation events but one. The one exception was apparently due to an incredibly unlikely occultation by 1989N2, one of Neptune's newly discovered satellites.

Voyager's computer sequences included a number of observations that could be retargetted to study new discoveries. Trajectory analysts on Voyager's Navigation Team worked feverishly to calculate the pointing positions neces-



The orbital locations of five of Neptune's newly discovered satellites, three rings, and a broad sheet of ring material are sketched here. (JPL 12383AC)

sary to image the thicker segments of the outer ring. The results were "spectacular!" and "right on the money" as in one case the image of a faint ring cut through the center reseau mark of the 800 by 800 pixel imaging frame.

Scientists knew that Voyager 2's search for tiny dust particles in the rings of Neptune would not be as sensitive as the search at Uranus because the spacecraft's flight path would be bending sharply downward to catch up to Triton, and therefore the phase angle* would not be as high as at Uranus. Nonetheless, they anxiously awaited the images to be taken in forward scattered light, when dust particles would be backlit by the Sun after the spacecraft was beyond Neptune. (As imaging scientist Dr. Carolyn Porco explained, an example of forward scattering occurs when you have a dirty windshield on your car, which does not become apparent until you drive toward the Sun, and the dust scatters the sunlight into your eyes.)

Although the highest phase-angle data was too badly smeared to yield immediate results, the much higher dust content of Neptune's rings (relative to the rings of Uranus) permitted lower phase-angle data to provide exciting results: a third ring, interior to the two narrow rings, which is diffuse and 1,000 kilometers (620 miles) wide. Like the middle ring and all but the three thicker segments of the outer ring, the third ring is too optically thin to have been detected from Earth-based occultation measurements. In addition to the third ring, images taken at a phase angle of 135° revealed a sheet of ring material that extends from inside the outer ring perhaps down to the atmosphere of the planet.

Neptune's rings appear to have much less large material than Uranus' rings do, and were not readily seen in radio science data. Some images appear to show "rocks" 10 to 20

* The angle between the incoming sunlight and the light emitted or reflected from the target.

kilometers in diameter embedded in the ring arc portion of the outer ring, but these may have been aggregates of smaller particles or even artifacts of the image processing. The sizes of the ring particles were difficult to ascertain immediately, and the imaging, photopolarimetry, ultraviolet spectrometry, and radio science teams are continuing to study their data.

Yet another investigation observed the rings: the plasma wave subsystem (PWS). The PWS was not originally designed as a dust detector, noted principal investigator Dr. Don Gurnett, but at Saturn it was discovered that the instrument is a very effective detector of dust impacts. The PWS recorded dust impacts on the spacecraft on both the inbound and outbound crossings of Neptune's ring plane , just as it did at Saturn and Uranus.

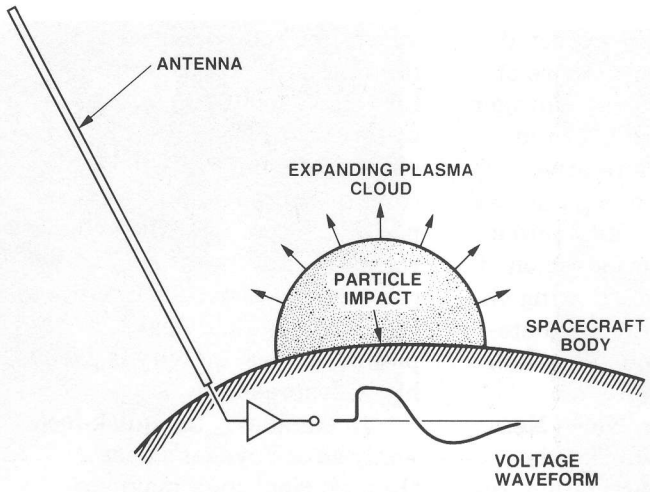
As the spacecraft swept through the ring plane at a velocity of about 12 meters per second, particles impacted the spacecraft in microexplosions, completely vaporizing and producing temperatures up to 100,000 degrees and ionized gases. These created voltage pulses that the PWS could record.

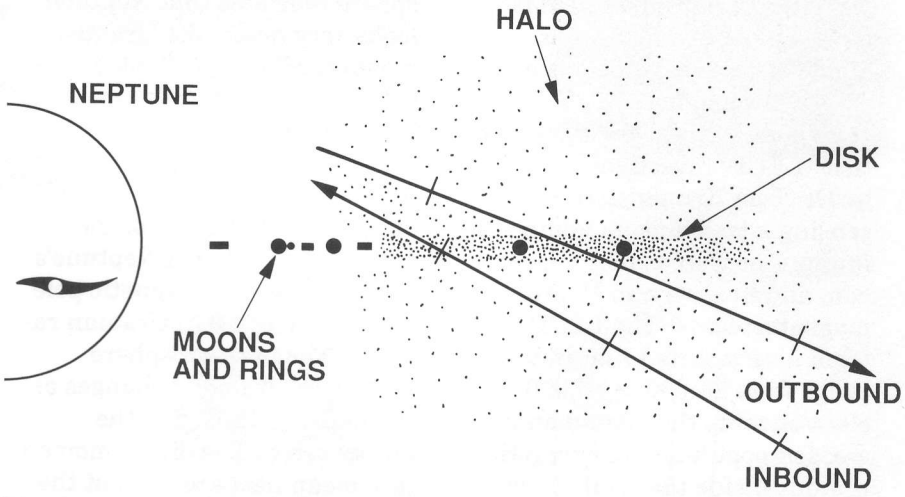
"We started detecting dust impacts about two hours before [inbound] ring plane crossing," said Dr. Gurnett. "Watching our data display in real time, we found it very scary as the impact rate went up, and continued for about 10 minutes."

Impacts were also seen for about two hours after the outbound ring plane crossing.

Dr. Gurnett said that there appears to be an intense disk with a dense concentration of particles. The maximum impact rate was 300 per second, corresponding to about three particles in each 1,000 cubic meters of space. The particles are probably about the size of those in smoke or clouds, and may be created by meteoritic impacts on larger ring particles and the moons.

Analysis of the Neptune data continues, and the conclusions of the first 30 days of data analysis are expected to be published in the December 15, 1989 issue of *Science* magazine.





Dust particles vaporize as they impact the spacecraft; the ionized gases create voltage pulses that are recorded by Voyager 2's plasma wave subsystem. Voyager 2 recorded impacts continuously for about one hour before and after ring plane crossing both inbound to and outbound from Neptune. (Top: JPL 12273BC; Bottom: JPL 12333BC)

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JPL 410-15-97 10/89

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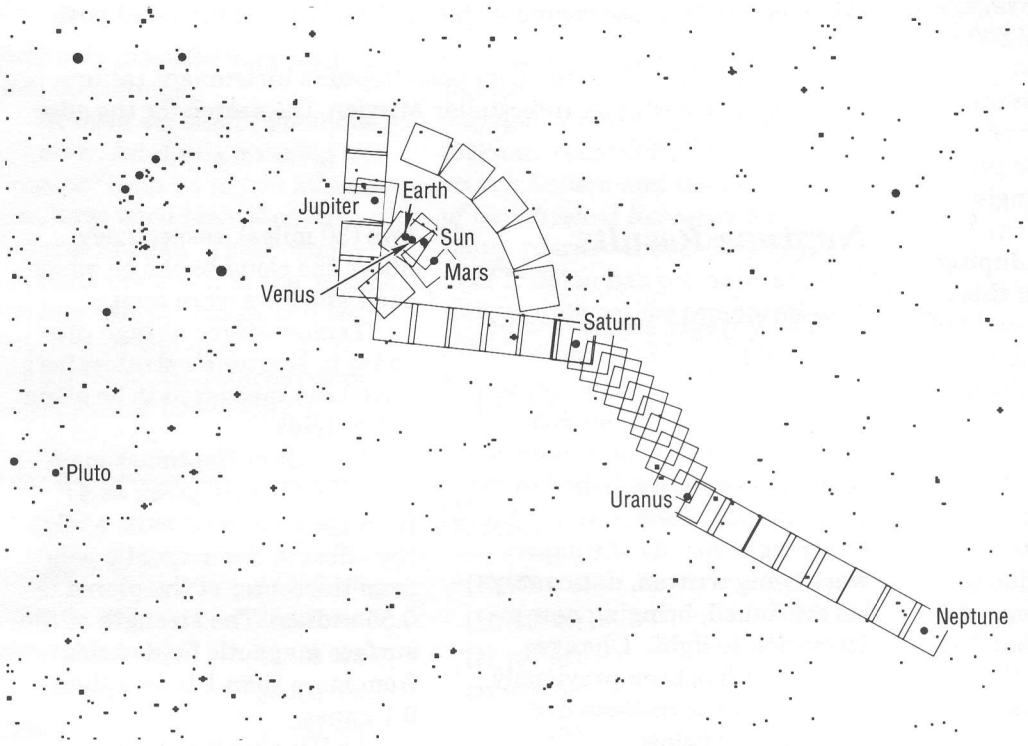
Voyager

BULLETIN

MISSION STATUS REPORT NO. 98 **JANUARY 29, 1990**



Voyager 1's unique vantage point will allow the spacecraft to sweep its cameras across the solar system, capturing images of most of the planets. The footprints of the wide-angle camera frames are shown.

Solar System Images: Say "Cheese!"

On February 14, Voyager 1 will take advantage of an historic and unique opportunity to image most of the solar system's planets, taking a final look back at where the Voyagers have been and showing Earth among its fellow planets.

Earth, Venus, Jupiter, Saturn, Uranus, and Neptune will be targeted in a sequence of wide- and narrow-angle images. Mars may be visible, but it will be a slim crescent close to the Sun, while Mercury will be masked in the Sun's glare. Pluto is too far away and too small to be imaged. From Voyager 1's viewpoint, the planets will appear to be clustered along the constellation Eridanus (The River).

Voyager 1 will be approximately 40 astronomical units (AU) from Earth and 32° above the ecliptic plane at an ecliptic longitude of 242°. A series of about 64 images will be taken, beginning with Neptune. The wide-angle frames will be taken through clear filters, while the narrow-angle frames, each centered on a planet, will be shuttered through blue, violet, and green filters. The spacecraft will roll to take images of regions that would otherwise be obscured by the spacecraft's high-gain antenna. Images of

the inner planets will be mosaicked around the Sun to avoid direct sunlight. The final wide-angle frame will be centered on the Sun.

Due to tracking schedules, the images will be recorded on board the spacecraft and returned to Earth in late March. Several weeks will then be needed to process the images to reveal as much detail as possible. Most of the planets will be smaller than a pixel in size; however, Jupiter may be as large as four pixels. (Voyager's imaging frame is 800-by-800 picture elements, or pixels.)

Due to the scale, it is unlikely that the entire set of images can be mosaicked to produce for publication a single photograph showing all the planets stretching from Jupiter to Neptune. A display of this mosaic would require a wall 100 to 150 feet long, depending on the chosen size of the individual prints. Imaging team members hope to release at least the central frames showing Earth, Venus, and perhaps Mars together.

Voyager 1 was chosen over Voyager 2 for this task due to operational considerations. Another factor is the fact that Jupiter would be too close to the Sun to be visible from Voyager 2's point of view this spring.

Although the ultraviolet spectrometer is still on, the sunlight will be too bright to allow observations during this imaging sequence. The infrared spectrometer and photopolarimeter instruments will not be on. The only potential damage from pointing these optical instruments too close to the Sun is that the shutter blades of the wide-angle camera might warp due to the increased heat of the sunlight focused on the blades.

Update

Contact with Voyager 1 has been normal since a partial loss of contact last fall. On October 23, Voyager 1 stopped sending its telemetry signal, by which science and engineering data are transmitted. The carrier signal, a single frequency used to track the spacecraft's location, continued. Commands were sent to reset the spacecraft's telemetry modulation unit. Controllers waited 11 hours for the signal to reach the spacecraft and a return signal to reach Earth before they knew that full contact had been restored. Flight controllers had no explanation for the one-time event, but there was some conjecture that it was related to high solar activity. Several other spacecraft also experienced computer problems during last fall's spate of huge solar flares. The high-speed particles ejected by solar flares can cause computer bits to "flip" from the desired position.

Voyager 2 has completed its post-Neptune instrument calibrations and has begun its Interstellar Mission, the search for the edge of the Sun's influence.

Neptune Results

The Voyager science teams have submitted their "30-day reports" on the Neptune encounter, as required in their contracts with NASA, and these reports have been published in the December 15, 1989, issue of *Science* magazine. As the papers were being written, data analysis continued, bringing new information to light. Changes from what has been previously reported in the *Bulletin* are summarized below.

Neptune's rotation rate is now cited as 16 hours 7 minutes ±1 minute, based on data from the planetary radio astronomy instrument.

Winds near the Great Dark Spot are now believed to be a rip-roaring 560 meters a second (1230 miles an hour), the strongest winds yet measured in the solar system. (Voyager measured winds on Saturn up to 500 meters a second or 1100 miles an hour.)

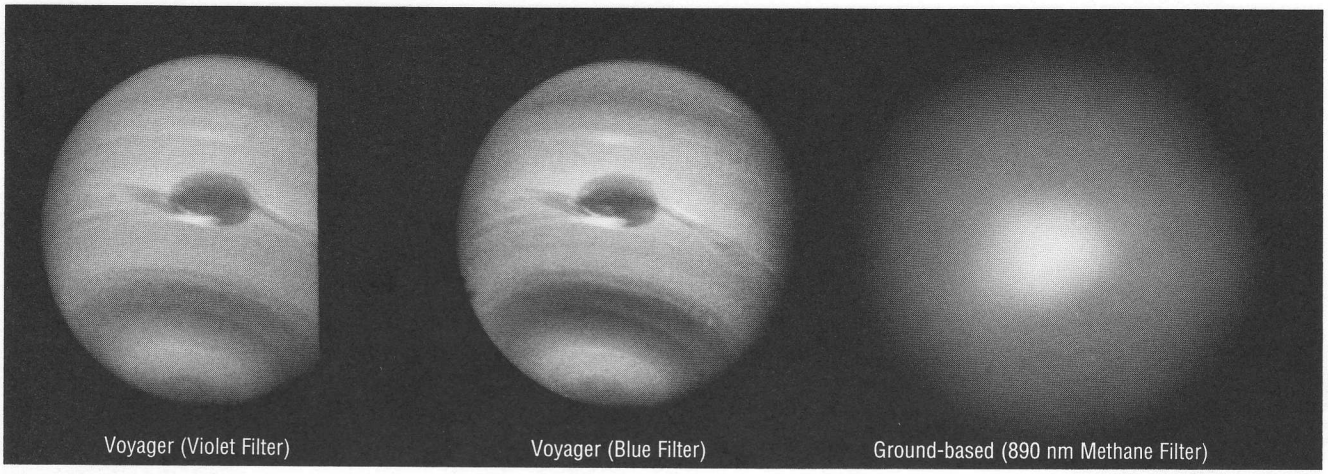
The cloud streaks seen near latitudes of 27°N and 71°S are estimated to be about 100 kilometers (60 miles) and 50 kilometers (30 miles), respectively, above the cloud banks on which their shadows were seen.

Temperatures at high altitudes in Neptune's stratosphere have been measured to be about 750 kelvins.

The tilt of Neptune's magnetic field is now given as 47° from the rotational axis, while the offset of the magnetic pole from the center of the planet is 0.55 radius. The strength of the surface magnetic field varies from more than 1 to less than 0.1 gauss.

As Voyager 2 passed through the ring plane, the maximum impact rate from ring particles was measured at 250 hits per second.

Triton's surface temperature has been revised to 38 kelvins (about -391°F), while the surface pressure is now believed to be about 14 microbars. Methane and nitrogen form a thin veneer on the moon's surface, while the underlying topographic features are suspected to be formed of water ice. Methane and nitrogen ices are too weak to support



Images of Neptune taken on August 24, 1989 indicate that the bright feature seen in ground-based images is the bright companion associated with the southern edge of the Great Dark Spot. (Right: University of Hawaii's 2.2-m telescope on Mauna Kea [Observer: H. Hammel].) (P-35061)

their own mass for very long in such formations.

At least six small, previously unknown satellites, ranging in diameter from 54 to 400 kilometers, have been identified in Voyager images. Their orbital elements are given in the accompanying table. Names will be assigned by the nomenclature committee of the International Astronomical Union (IAU).

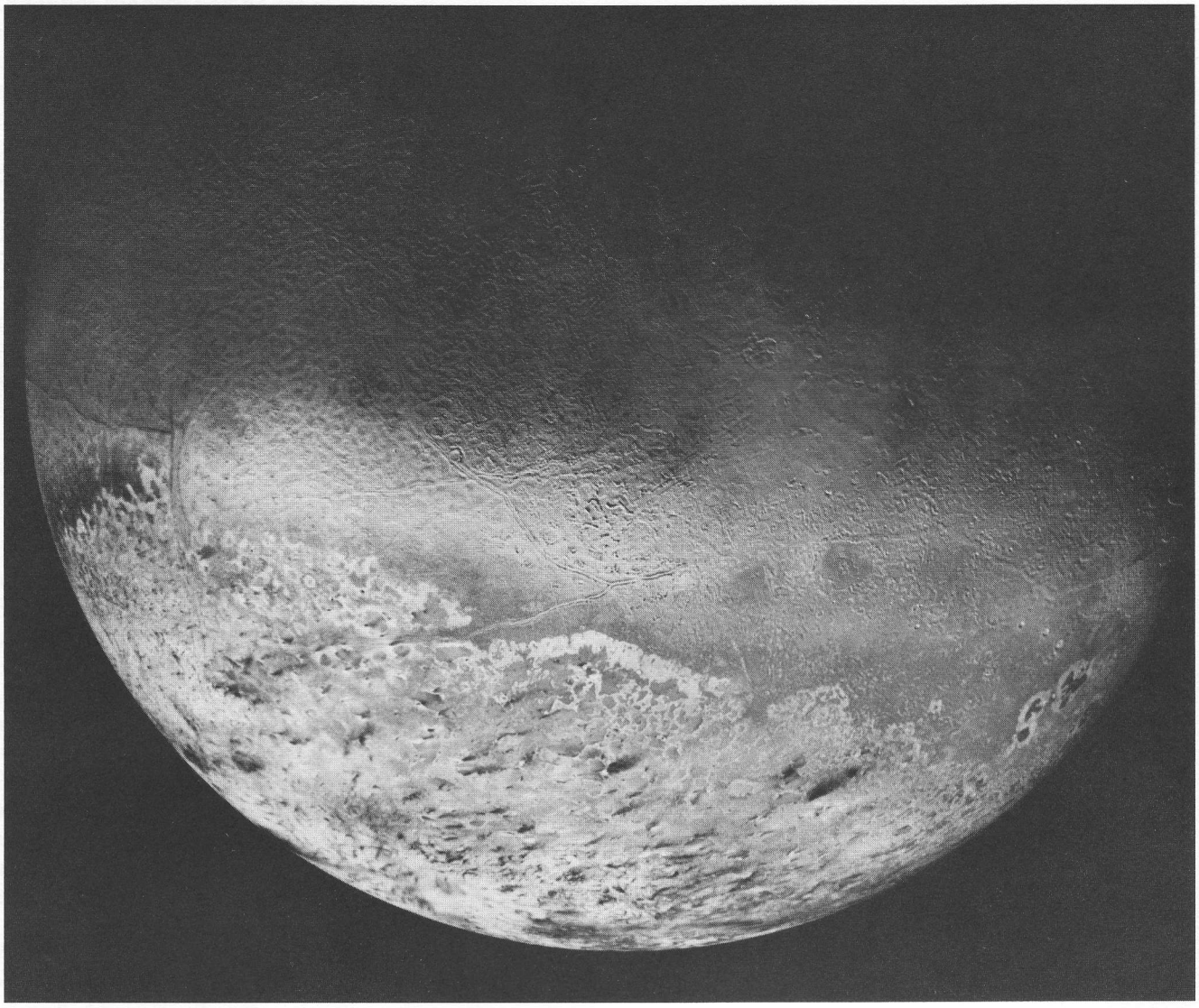
Researchers will continue to publish science results of the Voyager mission in professional journals such as *Geophysical Research Letters* and the *Journal of Geophysical Research* for many years to come. The Voyager mission has provided a unique data set for comparative planetology: four planetary systems studied by the same instruments.

Neptune's rings and moons.

Ring*	Orbital Radius (from Center of Neptune)**	
1989N3R	17,100 km	(10,600 mi)
1989N2R	28,400 km	(17,700 mi)
1989N4R inner edge	28,400 km	(21,100 mi)
1989N4R outer edge	34,200 km	(21,300 mi)
1989N1R	38,100 km	(23,700 mi)

Moon*	Orbital Radius (from Center of Neptune)**		Orbital Period	Diameter	
1989N6	48,000 km	(29,800 mi)	7 hrs 6 min	54 km	(33 mi)
1989N5	50,000 km	(31,100 mi)	7 hrs 30 min	80 km	(50 mi)
1989N3	52,500 km	(32,600 mi)	8 hrs	150 km	(90 mi)
1989N4	62,000 km	(38,500 mi)	10 hrs 18 min	180 km	(110 mi)
1989N2	73,600 km	(45,400 mi)	13 hrs 18 min	190 km	(120 mi)
1989N1	117,600 km	(73,100 mi)	26 hrs 54 min	400 km	(250 mi)
Triton	354,800 km	(220,500 mi)	5 days 21 hrs	2705 km	(1690 mi)
Nereid	5,488,600 km (avg)	(3,410,600 mi)	360 days 3 hrs	340 km	(210 mi)

* Moons or rings are numbered in order of discovery.
** Subtract one Neptune radius (24,764 km at 1 bar pressure level, at equator) to calculate distance from Neptune's cloud tops.



Voyager 2's highest resolution view of Triton was of the hemisphere that always faces Neptune. Most of the geologic structures on Triton's surface are likely formed of water ice, because nitrogen and methane ice are too soft to support much of their own weight. Several geyser-like vents spew nitrogen gas laced with extremely fine, dark particles. (P-35317)

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JPL 410-15-98 1/90

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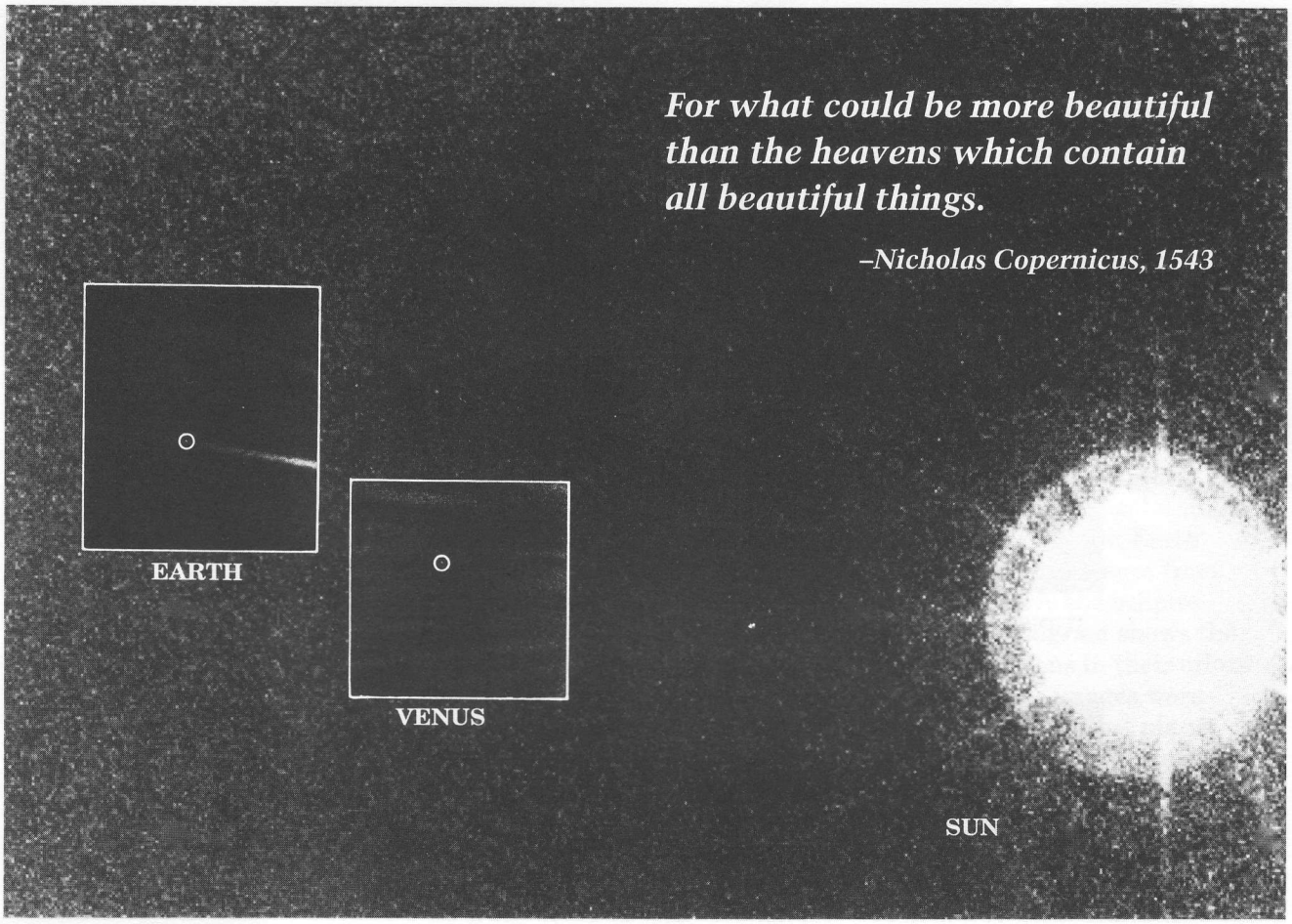
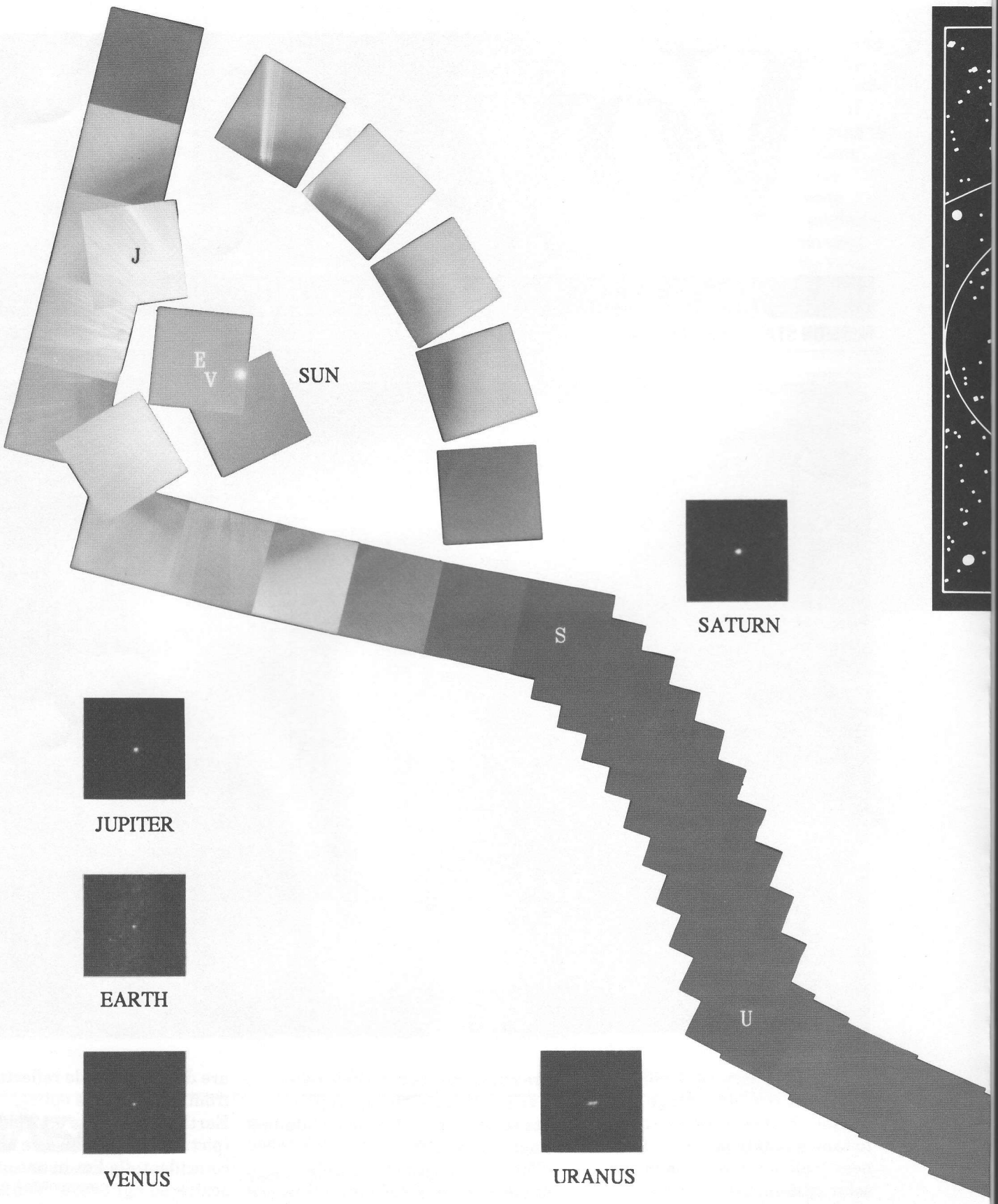
MISSION STATUS REPORT NO. 99 **JUNE 6, 1990**



On February 14, 1990, Voyager 1 took advantage of a unique and historic opportunity to take a family portrait of nearly all of the planets in our solar system. Above, images of the Earth and Venus taken with Voyager 1's 1500-mm focal length narrow-angle camera are superimposed in their relative positions at the appropriate scale on a portion of a wide-angle frame showing the Sun. (The focal length of the wide-angle camera is 200 mm). Due to its brightness, the Sun appears larger than the actual size of the solar disk; this also caused the ray patterns, which are due to multiple reflections from the camera's optics. Earth's crescent is 0.12 pixel (picture element) in size and coincidentally lies in one of the scattered light rays. Venus is 0.11 pixel in size. (A Voyager imaging frame is 800 x 800 pixels.)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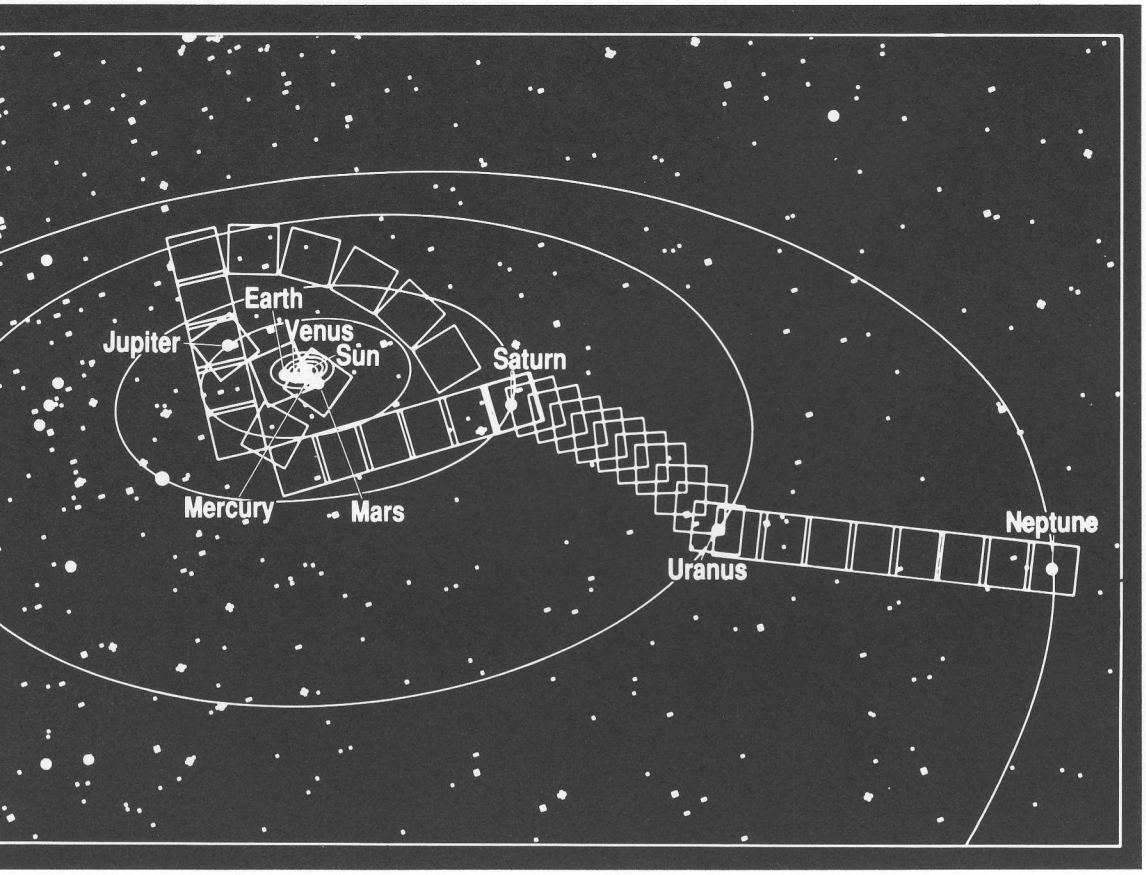
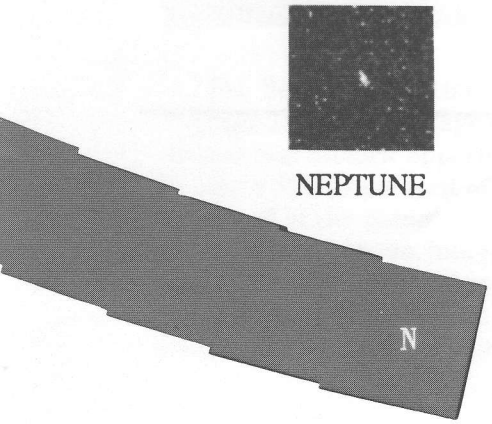




NEPTUNE

A mosaic of the 39 images taken by Voyager 1's wide-angle camera on February 14 links six of our solar system's nine planets; the insets are magnifications of the narrow-angle frames that were centered on the individual planets. Neptune, Uranus, Saturn, Jupiter, Earth, Venus, and the Sun are visible in this set of images. Mercury was masked by the Sun's glare, while the signal level in the Mars narrow-angle images was so low that the planet has not been positively identified. Pluto was too small, too dark, and too far away to be imaged. Detailed analysis suggests that Voyager 1 detected Earth's Moon, but it is too faint to be seen without special processing. The images close to the Sun contain scattered sunlight.

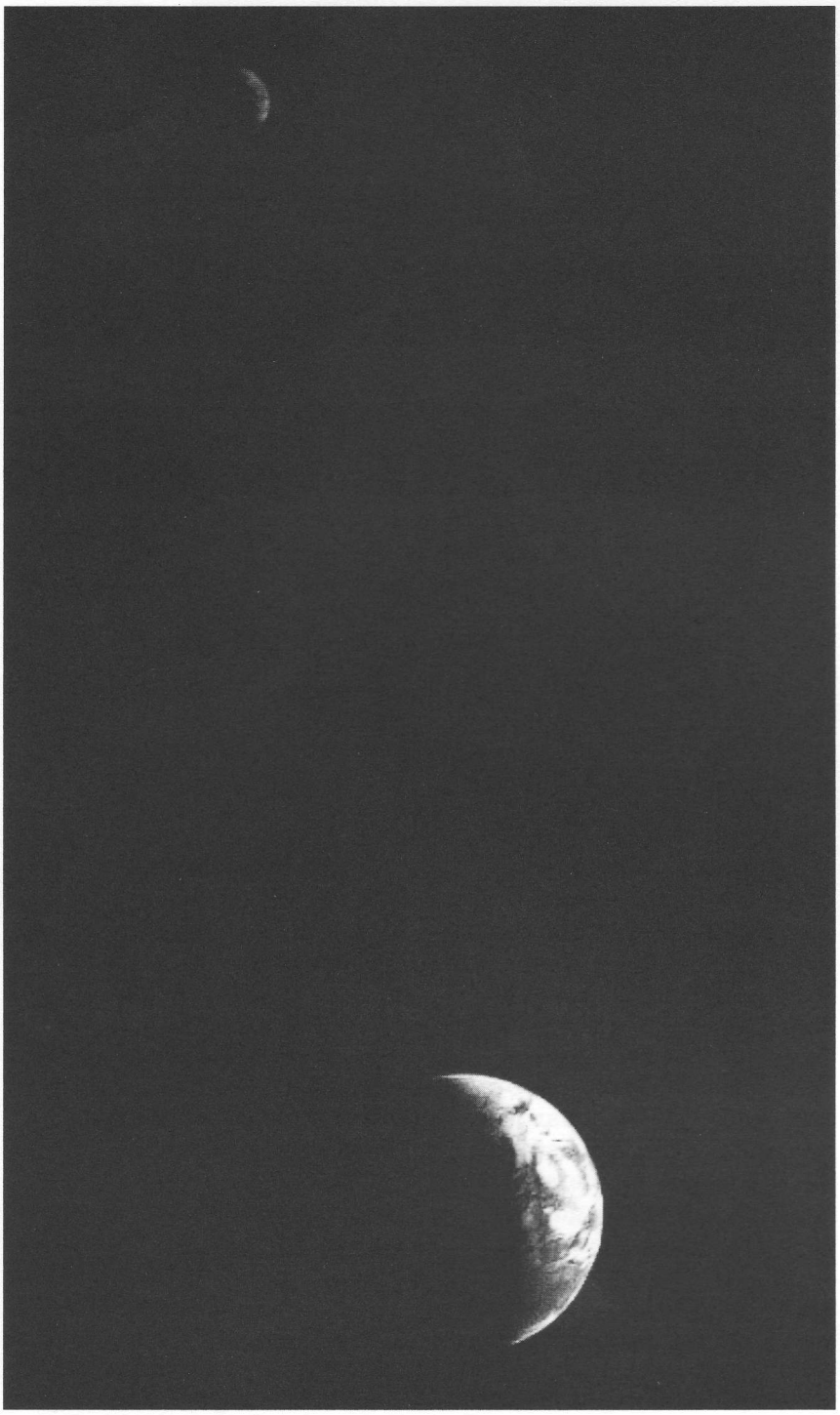
Jupiter's image is larger than a narrow-angle pixel and is clearly resolved, as is the image of Saturn with its rings. The images of Uranus and Neptune are smeared due to the spacecraft's motion during the long (15-second) exposures for these two images.

Voyager 1 was approximately 40 astronomical units or 3.7 billion miles from Earth when it took the images from about 32° above the ecliptic plane. The diagram shows the planets' locations in their orbits at the time the images were taken. The outermost planet shown, Neptune, is 30 times farther from the Sun than Earth is.

Primarily due to the Deep Space Network's tracking schedules, the images were recorded on board Voyager 1 and relayed to Earth in a series of playbacks in late March, in April, and in early May.

The wide-angle frames were taken through the clear filter, while three narrow-angle frames—using blue, violet and green filters—were taken of each planet so that color images could be reconstructed on Earth.

The mosaic was created by starting at Neptune, working in



to Uranus and Saturn, passing horizontally below and vertically to the left of the Sun, arcing above and to the right of the Sun, and finally jumping to the frames containing Mars, Jupiter, and Earth-Venus. These 60 frames—39 wide angles and 21 narrow angles—are the last of approximately 67,000 images taken by Voyagers 1 and 2 over the 12-1/2 years since their launches in late summer 1977. Voyager 1 flew by Jupiter (1979) and Saturn (1980), while Voyager 2 flew by Jupiter (1979), Saturn (1981), Uranus (1986), and Neptune (1989).

As Voyager 1 presents us with its last images, it seems appropriate to revisit one of the first images it sent us—the first and so far the only image of the Earth and the Moon together in a single frame, taken on September 18, 1977, thirteen days after Voyager 1 was launched. Voyager 1 was about 11.66 million kilometers (7.25 million miles) from Earth. The Moon is at the top of the picture and beyond the Earth, as viewed by Voyager. In the picture are eastern Asia, the western Pacific Ocean, and part of the Arctic. The photo was made from three images taken through blue, green, and orange filters. Because the Earth is many times brighter than the Moon, the Moon has been artificially brightened by a factor of five relative to Earth so that both bodies would show clearly.

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JPL 410-15-99 6/90

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